Technical Report Documentation Page

1. REPORT No.
632638

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
The Determination of the Test Maximum Density with Nuclear Gages

5. REPORT DATE
February 1968

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Smith, Travis; Weber, W.G., Jr.; and Howe, D.R.

8. PERFORMING ORGANIZATION REPORT No.
632638

9. PERFORMING ORGANIZATION NAME AND ADDRESS
State of California
Department of Public Works
Division of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

13. TYPE OF REPORT & PERIOD COVERED

12. SPONSORING AGENCY NAME AND ADDRESS

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A study to determine the feasibility of using nuclear gages to obtain test maximum density of soils used in highway construction is reported. An experimental compaction mold, large enough to allow use of a nuclear gage on the compacted specimen, was used in conjunction with nuclear gages to obtain the moisture-density relationship of soils. Test maximum density was reported in terms of count ratio. Since the same soil would be measured in the field also in terms of count ratio, gage calibration would be unnecessary. Both backscatter and direct transmission measurements were made with the latter showing a lesser variability. Results of the study indicate that the basic idea is feasible but largely impractical. There are technical problems which must be resolved before the concept could be implemented as a practical compaction testing procedure.

The study also involved the California moisture density (CMD) device. This apparatus, used with adapted nuclear equipment, did not yield the precision necessary for control testing purposes.

17. KEYWORDS
Soils, nuclear moisture-density determinations, compaction, compaction control, testing equipment, construction control

18. No. OF PAGES:
90

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1968/68-33.pdf

20. FILE NAME
68-33.pdf

HIGHWAY RESEARCH REPORT

THE DETERMINATION OF THE TEST MAXIMUM DENSITY WITH NUCLEAR GAGES

68-33

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632638

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads February, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

February 1968

Final Report
M&R No. 632638
Fed. No. F-4-2

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

DETERMINATION OF THE

TEST MAXIMUM DENSITY

WITH

NUCLEAR GAUGES

TRAVIS SMITH
Principal Investigator

W. G. WEBER, JR., and D. R. HOWE
Co-Investigators

Assisted By
B. L. Lister
C. T. Gipson

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ACKNOWLEDGMENT

This report covers a research project undertaken by the Materials and Research Department with the cooperation of various district construction departments and their resident engineers. This study was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration, U.S. Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the authors and the California Division of Highways and not necessarily those of the Bureau of Public Roads.

REFERENCE: Smith, Travis; Weber, W. G., Jr.; and Howe, D. R. "The Determination of the Test Maximum Density with Nuclear Gages," State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 632638, February 1968.

ABSTRACT: A study to determine the feasibility of using nuclear gages to obtain test maximum density of soils used in highway construction is reported. An experimental compaction mold, large enough to allow use of a nuclear gage on the compacted specimen, was used in conjunction with nuclear gages to obtain the moisture-density relationship of soils. Test maximum density was reported in terms of count ratio. Since the same soil would be measured in the field, also in terms of count ratio, gage calibration would be unnecessary. Both backscatter and direct transmission measurements were made with the latter showing a lesser variability. Results of the study indicate that the basic idea is feasible but largely impractical. There are technical problems which must be resolved before the concept could be implemented as a practical compaction testing procedure.

The study also involved the California moisture density (CMD) device. This apparatus, used with adapted nuclear equipment, did not yield the precision necessary for control testing purposes.

KEY WORDS: Soils, nuclear moisture-density determinations, compaction, compaction control, testing equipment, construction control.

CONTENTS

INTRODUCTION

With the current high rate of highway earthwork production, there is the ever present need to improve the efficiency of field compaction testing. Traditionally, the California Division of Highways has utilized the relative compaction concept for specifying minimum levels of compaction to be attained by the contractors in their construction operations. The test method, by which relative compaction is evaluated, for this purpose, involves in-place sand volume and laboratory impact compaction tests (Test Method No. Calif. 216). While these tests have served well, in years past, production rates have now increased to the point where it is difficult to obtain sufficient test coverage for full assurance of adequate compaction testing. As a consequence it has been evident that modification of the existing tests or the development of a new approach to compaction testing is desirable.

Considerable improvement in compaction coverage has recently been effected by the adoption of the test method entitled "Method of Test for Relative Compaction of Soils by the Area Concept Utilizing Nuclear Gages" (Test Method No. Calif. 231). This method specifies the obtaining of six (or more) in-place nuclear density tests. These six tests are obtained in about the same time period that it normally takes to perform one sand volume test. However, the speed with which the relative compaction results can be obtained is still heavily dependent upon the time it takes to determine the maximum density standard by the present laboratory test.

In order to reduce the time required to perform this portion of the relative compaction test, several ideas have been explored regarding the possible application of nuclear gages to determine the maximum density. One approach was that the maximum density condition could be established as a standard directly in terms of nuclear count ratio*, rather than in density units. Since the nuclear count ratio diminishes as soil density increases, the lowest count ratio obtained on a series of specimens fabricated above and below optimum moisture would represent the highest density condition. This then could be used as the standard to which the field in-place count ratios would be compared.

To accomplish this, it would be necessary to devise a special mold and a method of compacting the soil within the mold. The mold would need to be of adequate size to accommodate the same portable nuclear probe as used for the in-place field densities. Compactive efforts for fabrication of the specimens should be arranged to provide 90 or 95% of the density which

---

*Count ratio is defined as the ratio of the test nuclear count to the standard nuclear count (See Test Method No. Calif. 231-C).

would normally be indicated by the present standards.

If this manner of compaction testing could be developed, it could shorten testing time and improve accuracy by two principle means. First, it would relate field compaction directly to the compaction standard with the same soil properties being measured by the same equipment. Secondly, it would eliminate the presently required calibration of the nuclear gage since this would be accomplished at the time the lowest count ratio was being determined on the mold specimens.

It was decided in the fall of 1964 to undertake a research project aimed at developing a new test concept along these lines. To accomplish this, an experimental mold was designed for use with the nuclear gage and a program of field and laboratory sampling and testing established. Field operations were conducted on 36 construction projects in six highway districts. These operations consisted of performing in-place density and moisture tests at random locations using the nuclear gage. This was followed by sand volume tests (Test Method No. Calif. 216) at each site. Large samples of the various soils tested were then taken to the laboratory in sealed containers for compaction and subsequent nuclear testing in the big mold. The present standard California Impact Compaction Test was also performed on these samples.

It was felt that this research should also be concerned with the observation that the standard California impact densities, for certain soils, appear to be somewhat unrealistic with respect to soil behavior under field compaction. This has been evidenced by the fact that extreme difficulty is often experienced with clay materials in meeting current compaction requirements. On the other hand, sands often easily exceed requirements with the expenditure of very little compactive effort.

These findings recently led to the development of a new laboratory compaction apparatus called the California Moisture-Density Device, or more simply the CMD device (7). This device employs a flexible diaphragm and hydraulic arrangement, which is intended to provide for movement of the soil under the impact of a drop hammer. Previous research studies appeared to indicate that this device would develop somewhat lower maximum density than the impact test for clays and equal or somewhat higher densities for sands. Since it was felt these characteristics were desirable and also since the apparatus could be modified to obtain direct nuclear count-ratios, it was decided to include the CMD device in this study. It was hoped that this unique test method of determining a compaction standard might work well with the plan devised for this research program.

It is the purpose of this report to present an analysis of the findings from this extensive undertaking and to arrive at a determination of the technical feasibility of the proposed new concept for compaction testing.

CONCLUSIONS AND RECOMMENDATIONS

1. Evaluation of the acceptability of construction compaction directly in terms of nuclear count ratios through the use of the experimental mold is technically feasible although largely impractical at present.

2. Before further application to compaction testing can be made, the method discussed herein must be modified or adjusted in several ways. First, the geometrics of the experimental mold should be changed to minimize nuclear boundary effects and bring the laboratory calibration into conformance with field calibration. Secondly, the compactive effort applied to the specimens in the experimental mold should be altered to attain the desired level of density relative to the impact compaction test. Finally, the inordinate amount of time and labor required to fabricate the large test specimens must be reduced. In addition, the possibilities of improving the orientation of the soil particles in the mold by the application of a kneading-like compactive effort should be explored.

3. It is recommended that further research be considered to investigate the relative merit or continuing as outlined above, or proceeding in some other direction. Particular consideration should be given to desirable accuracy or reproducibility, necessary calibration frequency, time and labor requirements and economy in terms of number of tests per unit time.

4. Application of the California Moisture-Density (CMD) device in this study encountered several difficulties. The difficulties encountered were in nuclear equipment, and in the apparent inability of the device to provide the desired discrimination between clays and sands. Extensive modification of the nuclear equipment and extensive backup data would be necessary if further work is done with this equipment. In addition to successful equipment modification there would still be the need to use two independent nuclear gages which would defeat one of the objectives of this study. It does not appear desirable to pursue the study of this device further.

DESCRIPTION OF TEST APPARATUS

This program required the use of various test apparatus, some of which is standard equipment presently used by the California Division of Highways, and some is experimental.

The need to correlate the results of this study with the present test method, required the utilization of the sand volume in-place density apparatus and the California Impact Compaction test equipment.

Three nuclear gages were used in this study. One set of nuclear gages used was the Nuclear-Chicago Model P-22 surface density probe and Model P-21 surface moisture probe. The P-22 has a 3 millicurie (mc) source of Cesium 137, the P-21 uses 5 mc of Radium-Beryllium as the source of radiation. Both of these backscatter type probes connect to a Model 2800 scaler by 20-foot cables. The Nuclear-Chicago equipment is shown in Photo 47. The second nuclear gage used was the Hidrodensimeter Model HDM-2 (photo 48). This is a combination backscatter and transmission density probe and backscatter moisture probe. The combined gage has a 5 mc source of Radium-Beryllium. The probe and scaler are connected by a 50-foot cable. The third nuclear probe was specially built for the CMD apparatus and has a 100-microcurie source of Cesium 137. The Nuclear-Chicago scaler records the impulses from this probe. The probe is an integral part of the California Soil Moisture-Density (CMD) mold (Photo 49).

The experimental mold was fabricated of plate and channel steel. The inside dimensions of this mold are 15 inches long by 6 inches wide by 6 inches deep. It was thought this would provide sufficient volume (0.23 to 0.29 cu ft) to accommodate existing nuclear soil gages for determination of the moisture and density of the compacted material. Due to its size, and for purposes of identification in this report, this mold is referred to as the Big Mold. The ten-pound tamper is of the drop hammer type falling two feet onto a foot 4 inches square. Photo 51 illustrates the Big Mold and the test procedure is presented in Appendix B.

The other experimental mold, used in this study, is part of the CMD device. This mold is of stainless steel seven inches high and approximately six inches in diameter. The side of the mold has been relieved to one-sixteenth inch thickness where the nuclear gage is affixed. The mold has a two-inch diameter by four-inch high rubber diaphragm in the center, in which hydraulic pressure is maintained. The ten-pound tamper is of the drop hammer type and falls 18 inches to a 3.1 square inch foot. The foot is in the shape of an annular ring. The sample volume for this mold is 0.059 to 0.067 cu ft. This apparatus is illustrated in Photo 50 and the test procedure is in Appendix A.

TESTING PROGRAM

This program was conducted in two phases. During the first phase, from December 1964 to April 1965, the Nuclear-Chicago instrument was used in the field testing and the laboratory work with the Big Mold. During this phase, the standard and test counts on the CMD apparatus were one minute each.

When a review of the data from the first phase was made it was found that calibration difficulties with the Nuclear-Chicago gage were being encountered. It was then decided to use a combination transmission-backscatter density gage to determine if the calibration problems could be corrected. This resulted in the undertaking of the second phase in this study.

In the second phase, from July 1965 to November 1965, the Hidrodensimeter was used in place of the Nuclear-Chicago gage. This divided the field and Big Mold data into two parts; backscatter (phase one), and backscatter and transmission (phase two). It was found during phase one that the calibration curve for the CMD apparatus had a very flat slope. In order to gain a steeper calibration curve, during the second phase, the standard counts were taken for two minutes and the test counts for five minutes. All other functions in the sampling and testing procedures remained the same in both phases.

In the preliminary stages of this research project, it was necessary to undertake some limited experimental testing in order to establish certain relationships in connection with the functioning of the Big Mold. One of the items examined was the requirement for shielding around the backside (i.e., side away from the test specimen) of the transmission detector rod. Another item was the determination of the compactive effort needed to attain the desired level of soil density in the mold. The details and findings of these preliminary experiments are discussed in another section of this report under "Analysis of Data."

The "field" testing in this research program was conducted in selected areas on going contracts where the contractor had presumably completed compaction. However, these particular areas had not necessarily been accepted by the resident engineer at the time of testing for this study. The pattern of in-place density and moisture testing was conducted in accordance with the area concept principles specified in Test Method No. Calif. 231-B. That is six sites were selected at random within the chosen area. In general the areas selected in this study were approximately 600 square feet in size. In addition to the nuclear testing, sand volume tests were performed at two of the nuclear test sites for the purpose of establishing field calibration relationships between in-place density (also moisture) and count ratio.

Upon completion of field testing, a large sample (approximately 500 lbs.) of soil was obtained from the area for the laboratory portion of the study. The sample was taken in such a manner as to represent the test sites in the area. All samples were transported to the laboratory in sealed containers to preserve the field moisture content.

At the laboratory the sample was thoroughly mixed, quartered and apportioned for the several tests which were to be performed. Three or more specimens were compacted in the Big Mold at moisture contents spanning the maximum density and using the compactive effort determined in the preliminary studies. Nuclear gage readings on each of these specimens were used to determine both the maximum density of the test series and the laboratory calibration relationship for comparison with field calibration. Specimens were also fabricated by impact compaction, in accordance with test method 216, to provide a comparison of the standard impact density and moisture values with the densities and moistures obtained in the Big Mold specimens.

A series of specimens, spanning optimum moisture were fabricated in the CMD apparatus with the intent of comparing with both impact compaction and the field in-place density tests. Unfortunately, difficulties in obtaining reproducibility of nuclear readings, during the calibration stage of this test, made the fulfillment of this objective difficult. This problem is discussed in the section under "Analysis of Data."

The respective procedures for performing the tests with each type of mold are shown in Appendices A and B.

ANALYSIS OF DATA

General Remarks

Theory and practical experience have revealed that when nuclear density determinations are taken, the lowest counts indicate the highest density measured. This fact is illustrated in Figures 7 to 41, in which the conventional Moisture-Density curves are compared to the density count ratio moisture curves.

By determining the minimum density count ratio it is thus possible to determine the maximum wet density of the soil. The use of one and one-half inch maximum size material, instead of the usual 3/4 inch, will also reduce the frequency where rock corrections are required in the field. The wet method of determining the maximum test density can then generally be utilized. However, where it is desirable to use dry densities the moisture content can be subtracted from the wet densities in the normal manner. From the figures it can be seen that the minimum count ratio was observed at the moisture content at which the peak density for the sample occurred.

The fact that the maximum wet density and the minimum count ratio were at the same moisture content indicates that the nuclear gages were in fact measuring the maximum density of the soil. Also the maximum density as determined by the standard impact test and the big mold occurred at about the same optimum moisture content which indicates the correlation of the two methods.

The entire validity of the concept of utilizing the nuclear gages to determine the maximum density depended upon reproducing the standard impact test with the nuclear gages. This was accomplished in this study. As the count ratio was to then be used directly to accept or reject the compacted earthwork it was necessary to have the resulting nuclear count ratio at about 90 or 95 percent of the standard impact density. The mold and field calibration curves also must be identical so that the mold count ratios would relate directly to the count ratios determined in the field. Also the nuclear test method must be reproducible and all potential sources of errors investigated. The various sources of errors are discussed in the following sections of this report.

Big Mold Design

In the development of the Big Mold, the question arose as to the desirable geometry of the radiation shield over the transmission detector rod (See Photo 52). The purpose of this shield is to eliminate background radiation from affecting the density readings and to account for the gamma radiation which would be reflected if the soil was behind the detector. The lack of soil to shield the detector from background radiation would increase the test count. Conversely the lack of soil behind the detector to reflect the gamma radiation would decrease the count. It was felt that the latter effect would be the most important. To study this effect three shields were made (See Photo 53); one resembles a "U" with parallel sides; the second shield was constructed by opening the "U" 60 degrees; the third was opened 120 degrees. The "U" shaped shield with parallel sides was used on all routine tests. On several specimens of different densities and soil type, experiments were performed to compare the effect of each of these shields along with the situation where no shield is provided. This data is shown in Table II. The data indicates that the straight sides tended to shield the detector from the gamma radiation from the source, with the counts increasing as the "U" was opened up. This study indicates the advisability of drilling a hole in the compacted soil so that the same condition exists in the test sample as in the field measurements. In reviewing the calibration curves obtained in the field and from the test samples it can be seen that the use of the "U" + 120° shaped shield would have resulted in the 6-inch mold calibration curve approaching the 6-inch field calibration curve. It is believed that the use of a drilled hole in the compacted soil sample will result in the two calibration curves approaching one another.

Another study performed with the Big Mold and the nuclear gages was an attempt to determine if the length of core affected the nuclear counts. In Phase I this was accomplished by moving the probe in 1/2 inch increments towards the ends and sides of the mold. In Phase II, because of the transmission rod, an extra long core was prepared and successive 1/2 inch portions were cut or sliced off between the nuclear determinations. This data appears in Table III. From this study it was decided that no hard and fast rule for core length could be applied. The operator must know the gage he is working with, and therefore knows the location of the source and detector tubes in the probe. Knowing these facts one should not prepare a core shorter in length than the distance between the source and detector tubes plus 1½ inches. It has already been established that the width of the mold is sufficient, but reasonable care should be employed to center the probe on the specimen. The data does indicate that the specimen should be fabricated to a length of at least 13 inches. This is no problem as with practice all cores can be prepared at approximately the same length.

Calibration

A primary consideration in this study is the comparison of field calibration of nuclear gages with the calibration obtained using the gages on the Big Mold specimens. This is desirable so as to have the nuclear count ratios relate to the same density on the Big Mold as they do in the field. In this way the field count ratios can be compared directly to the minimum count ratio obtained from the Big Mold tests. If the calibrations are not the same, it would be necessary for field control purposes to establish both field and laboratory calibrations. The following analysis is a comparison of the two types of calibration along with an examination of the reproducibility of the data.

The gages were calibrated using the field data, that is the nuclear readings obtained in the field were compared to the densities or moistures obtained by the sand volume test. This relationship of the nuclear readings to the soil moisture or density is shown in Figures No. 1 to 5. These calibration curves were used to determine the soil moisture and density where the nuclear tests were conducted.

The in-place field nuclear readings were plotted against the indicated wet density to form calibration curves. These are straight lines calculated by a least squares regression analysis for the best fit line from the data. The backscatter type instrument used in Phase I showed a standard deviation of about 9 lbs. per cu. ft. using 16 points. The Phase II instrument indicated a standard deviation of about 7 lbs. per cu. ft. using 34 points in the backscatter position. The calibration curves for Phase I and Phase II backscatter gages are shown in Figures 1 and 2, respectively. Previous studies have shown that soil type has a marked effect on backscatter measurements (1)(2). No effort was made in this study to obtain calibration curves for the different soil types; but if separate curves were obtained previous work indicates that the standard deviation would be about 4 to 6 lbs. per cu. ft. for both gages.

Nuclear density determinations were also obtained at transmission depths of 6 and 10 inches in the field and compared to the density determined by the sand volume test. The plots of this data are shown in Figure 3. The field calibration curves indicate a standard deviation of about 6 lbs. per cu. ft. for both depths of measurement. This deviation from the value usually accepted for transmission gages (2 to 3 lbs. per cu. ft.) is explained by the different volumes of measurement, nonuniform soil conditions, and the types of material tested in this study(3).

The field moisture content correlation indicated a standard deviation of about 1.5 lbs. of water per cu. ft. of soil in Phase I; and in Phase II about 2 lbs. of water per cu. ft. of soil. These figures agree with studies previously performed to determine the accuracy of the nuclear gages in obtaining moisture content(2). The curves for the moisture correlation are shown in Figures 4 and 5.

The calibration of the nuclear gages was also obtained from the compacted soil in the various experimental molds. These comparisons are labeled as laboratory calibrations so as to differentiate them from the above field calibration data. These laboratory comparisons are shown in Figures 1 to 5 for the Big Mold and in Figure 6 for the CMD apparatus.

Before comparing the nuclear readings to the mold densities, one should know the reliability of the mold densities. Table I indicates the mold densities for those soil samples which had two specimens prepared at similar moisture contents. Approximately 75% of these points occurred by chance. This data indicates that the test procedure is reproducible to within $\pm$ 1.5 lb. per cu. ft. 95% of the time.

Laboratory correlation was performed by plotting the nuclear density readings against the mold wet density. Moisture content determinations were correlated by the oven dry method. The backscatter gage used in Phase I had a density standard deviation of about 4.5 lb. per cu. ft. on the compacted soils in the mold. The density calibration curve established for the Phase II backscatter instrument indicated a standard deviation of about 3 lbs. per cu. ft. As shown in Figures 1 and 2 the mold calibration curve is somewhat departed from the field data. This is due to the effect of the sample size and boundary conditions upon the readings. It was necessary to keep the mold sides and ends on while taking the nuclear readings; as it was found that some samples crumble quite badly as the mold is disassembled and the gage positioned. Therefore, it was decided to leave the mold together for all samples. It also appears that the slope of the mold calibration curve in Figure 1 is more in following with the manufacturer's suggested curve for this instrument.

The transmission correlation indicated a standard deviation of less than 2 lbs. per cu. ft. on the mold at a six inch depth. The curve for this data is shown in Figure 3. It is felt that the better all around conditions encountered in the laboratory, as compared to those in the field, is the reason for the closer correlation. Some of these conditions are: better seating of the gages on the mold and more uniform density throughout the mold.

Figure 46 shows a frequency distribution for the data in Figures 2 and 3. Attention is called, in Figure 46 A and B, to the almost normal "bell" curve formed by the transmission readings on the mold. It is felt that the backscatter calibration data using the mold would approach a normal distribution if the soil types had been classified. This would mean a field and mold calibration curve for each general soil type on a project for the backscatter instruments.

The nuclear moisture determination on the mold samples are shown in Figures 4 and 5. The nuclear moistures are about 10 lbs. of water per cu. ft. high in both Phase I and II. The field and mold correlation curves are approximately parallel.

The reason for this offset between the moisture curves is the relatively small size of the mold sample in regards to the size of sample measured by the nuclear gage. In designing the mold no attempt was made to make the mold large enough for agreement between the field and mold moisture calibration curves.

Nuclear counts were taken reversing the gage on the compacted specimen and averaged. This average of the counts was then converted to count ratio and plotted against the indicated mold density. It is believed that this averaging could have also introduced some error in the backscatter readings. A comparison of the nuclear readings from each reversal of the gage on the mold was performed to ascertain the reliability of this average.

The comparison for the backscatter gage showed a considerable difference in counts from one end to the other on the wetter specimens. This was caused by a "slump" of the sample when the end of the mold is removed. It was determined that the back-scatter gage had a standard deviation of 3 lbs. per cu. ft. on the reversed determinations. The transmission readings did not seem to be affected by this "slumping" of the sample and had a standard deviation of less than two lbs. per cu. ft. for the reversed density determinations. It is felt that the taking of readings at both positions can be eliminated and readings taken at one position with the mold end left on the compacted soil.

Field Application

A portion of this research project was to develop new test equipment and a method of determining relative compaction with nuclear gages. The accuracy, dependability and reliability of the equipment have been discussed. However, the final basis for acceptance is how the new equipment performed in accepting or rejecting compacted earthwork. It is shown in Table IV how this equipment (Big Mold) and method (See Appendix) compare to the existing Calif. Test Method Calif. 216-F. The correlation between the Big Mold and the existing method was poor due to selecting an incorrect compactive effort in the Big Mold. This will be discussed in the following section. In comparing the correlation between the various nuclear tests a good correlation was obtained. The backscatter and transmission types of nuclear measurements agree closely to each other. That is, on 3 of 17 samples the backscatter and transmission types failed to agree as to acceptance or rejection. This would be improved by a calibration curve for each general soil type for the backscatter type gage. Only once in 20 samples did the results from the 6 and 10-inch transmission depths disagree. It is felt that this indicates excellent consistency for the method and equipment.

Compactive Effort

An important aspect of this study concerns the relationship between the maximum density, obtained by the "Big Mold" method, and the present impact maximum density. In the design of the research program it was intended that a compactive effort would be employed on embankment materials in the Big Mold which would provide maximum densities at a level of 90% of that determined by the impact method. It was also desired to obtain maximum densities at a 95% level for structural section and other materials normally requiring 95% relative compaction.

As an aid in estimating the compactive effort needed, two samples, one composed of a river sand and the other of a heavy clay, were prepared and compacted separately in the Big Mold utilizing various compactive efforts. The effort was varied by the number of coverages per layer, with four blows of the tamper constituting one coverage. The standard impact compaction test was also performed on each material. The results of these preliminary experiments are shown in Figure 42.

It is noted in Figure 42 (A) that the semi-log plot of wet density versus compactive effort, on the river sand, generally indicates a straight line increase of density as the number of coverages increase above three. Assuming that this sand represents a material upon which 95% relative compaction is required in the field, then it appears that four coverages per layer would be suitable.

The same approach was followed with respect to the clay sample as shown in Figure 42-B. However this soil was presumed to represent materials for which a minimum of 90% relative compaction would be required in the field. It appears that the four coverages would also apparently provide values close to 90% relative compaction for this clay soil. In view of this evidence it was decided to use the compactive effort of four coverages per layer on all materials in the main study, regardless of field compaction requirements.

Upon completion of the testing in the main study, it was found that apparently this choice of compactive effort only partially fulfilled the desired objective. An evaluation of the project data is summarized in Tables V and VI for materials requiring 90% and 95% relative compaction, respectively.

The data in Table V indicate that materials, requiring 90% relative compaction, were compacted in the Big Mold to levels consistently higher than 90% of the impact densities. An indication of this is shown in column 5 where the ratio of the Big Mold to impact compaction maximum wet densities range from 94% to 100% and average 97%. Evidence of even greater significance is provided by a comparison of the degree to which the impact and Big Mold methods accept (or reject) field compaction. Referring to columns 7 and 9 in Table V, there are seven cases where areas would be accepted by the Impact Method, whereas there are only two acceptable areas by the Big Mold method. Of these two areas accepted by the Big Mold, each case has some tests indicating rejection (see column 8), even though the impact method would accept the areas by considerable margins.

In view of the above findings it appears that the standard of compaction established by the Big Mold in this study was excessively high for materials requiring 90% relative compaction. It is felt that a reduction of compactive effort in the Big Mold method is warranted for these materials.

Evaluation of the present impact and Big Mold maximum wet densities, indicates a somewhat better relationship between the two methods when materials requiring 95% relative compaction are being considered. Table VI shows a range in the ratio of the maximum wet densities (column 5) of 91% to 101% and an average of 96%. Four areas in the field testing were accepted by the impact method with two acceptable by the Big Mold method. Again this shows a tendency for the Big Mold to set a compaction standard at a level higher than that originally intended. However, it appears that there are a greater proportion of individual acceptable tests (see column 6) shown for 95% requirement materials than is indicated for 90% materials (in Table V). This would indicate a closer degree of agreement between the two methods, in this case, than was previously indicated. While the Big Mold admittedly appears to set a slightly higher compaction standard for 95% materials than the impact method, it is felt that the difference is not large enough to justify a reduction in compactive effort.

In the final analysis it appears possible that improvement may be effected in specimen compaction by altering the mode of compaction as well as the compactive effort. Compaction was accomplished in this study by the use of a 10-lb. drop hammer acting on a 4" x 4" foot. While this arrangement permits some lateral or plastic flow type of working of the soil the compactive effort is still applied fundamentally by impact. This means that the full load is only acting on the soil for a small fraction of a second. As the density achieved is influenced by the nature of the compactive effort, this leads to the belief that the application of a kneading-like compaction could be useful in attaining the desired density levels with Big Mold specimens.

Provision for kneading compaction could be made with a simple, hand-operated device, similar to that developed by Seed(6) and others. It is envisioned that a kneading compactor could be made at relatively low cost and be easily portable for field operations.

<u>Moisture Determinations</u>

The major time consuming item in the maximum density test procedure is the determination of the moisture content of the sample. This was eliminated in California, where no rock correction is required, in 1954 by the use of the Wet Method(5). This method does not require the determination of the sample moisture content, and can be used where no rock correction is required. The use of 1½ inch maximum size rock in the Big Mold would frequently eliminate the need for the use of a rock correction in highway construction, and the nuclear determination of density of the sample in the mold would be readily conducted. Where a rock correction is required both the moisture and density count ratios may be determined. Examples of this type of plot are shown in Figures 43 to 45.

In these plots the density count ratio is plotted against the moisture count ratio. The curves obtained from these data are similar to the curves obtained plotting density count ratio against oven dry moisture. This demonstrates the feasibility of using nuclear count ratios instead of oven drying the soil. This would reduce the time required when the dry density is required. The dry density would be obtained by converting the wet density and moistures to pounds per cubic foot respectively. Then the moisture would be subtracted from the wet density to give the desired dry density. Using the indicated rock correction the field dry density would be obtained.

Where it is desired to use the wet method the minimum count ratio for the wet density would be used in the field. This would eliminate the need to obtain oven dry samples or the measurement of the amount of water added or subtracted from the soil.

California Moisture-Density Device

The outcome of the study with respect to the CMD device was rather disappointing in two primary aspects. First, there were calibration problems, basic to nuclear measurements which could not be completely resolved by procedural changes. Secondly, the data obtained did not appreciably reflect the discrimination between clays and sands, in terms of maximum density determinations, as was indicated in previous studies.(7)

The calibration problem, which involves the correlation of nuclear counts with mold density, concerns the sensitivity of the gamma rays to changes in density. In Phase I a one-minute standard and test count was taken. When the resulting count ratio was plotted against the mold density the count ratio was relatively insensitive to a change in density. This is shown in Figure 6A. The change in count ratio was 0.05 for a density change of 50 lbs. per cu. ft. or a ten lbs. per cu. ft. density change produced a change of 0.01 in the count ratio. The standard deviation for this curve is about 13 lbs. per cu. ft. In an endeavor to obtain more definition from this device in Phase II of this study the standard count was taken for a two-minute interval and the test count for five minutes. This count ratio was plotted against the mold density and produced the curve shown in Figure 6B. The standard deviation for Phase II is about 8 lbs. per cu. ft. and the slope of the curve is less flat than in Phase I. The change in count ratio was 0.20 for a density change of 60 lbs. per cu. ft. or a ten lbs. per cu. ft. density change produced a change of 0.03 in the count ratio. While this procedural change improved the calibration curve to some degree, it is felt that it has insufficient sensitivity and reproducibility for practical field application.

The backscatter type of density measurement was used in the CMD studies. The mass of high density material in the mold had considerable influence on the test counts, even though the thickness of the metal was reduced at the source and detector. From another viewpoint the compacted soil was affecting only a small portion of the gamma rays reaching the detector in relation to the number affected by the mold, and other material within the sphere of influence. The original intent when this nuclear gage was constructed was to remove the sample from the mold and then determine its density. However the compacted soil expanded when removed from the mold resulting in invalid readings. Considerations have been given to using a transmission type of nuclear gage with the CMD device. However the influence of the material within the sphere of influence would continue to exist, though possibly at a reduced level. The value of modifying this mold for further work is difficult to determine at the present time.

Another item of the calibration problem concerns the fact that the calibration curve for the CMD device does not correspond to the curves for the field nuclear gages. This is demonstrated by a comparison of Figure 6B with Figures 2 and 3. This obviates the advantage of directly relating count ratios to minimum mold count ratio for compaction. Unfortunately, the question is largely a matter of the basic difference in nuclear geometrics between the field and laboratory gages. It is not likely that this can be resolved without major changes in both types of gages, and this would be undesirable from an economic standpoint.

Comparison of CMD maximum dry densities with respective values from Calif. Impact tests, is shown in Figure 54. In this scatter diagram the various materials, tested in the study, are classified by soil type and represented by appropriate symbols. It is noted from the figure that while there is an overall trend for the CMD densities to be lower than those for Calif. Impact test, there is no real discernible difference between the sand and clay materials. It appears that both types of soils generally develop a similar pattern of CMD densities with respect to the Calif. Impact densities. This is further illustrated by the frequency distribution chart of test variations shown in Figure 55.

In summarizing the CMD portion of the main study, it does not appear feasible to undertake further investigation with this device. The calibration difficulties in combination with the apparent inability to achieve the desired different relative density levels for clays and sands does not make the method advantageous for compaction control.

REFERENCES

(1) Hughes, C. S., and Anday, M. D. "Correlation and Conference of Portable Nuclear Density and Moisture Systems" Highway Research Record No. 177 HRB 1967.

(2) Weber, W. G., "Laboratory and Field Evaluation on Nuclear Surface Gages for Determining Soil Moisture and Density," HRB Record No. 66, January 1964.

(3) "A Basic Study of the Nuclear Determination of Moisture and Density," A Materials and Research Department Report, California Division of Highways, November 1965.

(4) Weber, W. G., and Smith, T., "Practical Application of the Area Concept to Compaction Control Using Nuclear Gages," presented at the January 1967 HRB meeting.

(5) California Division of Highways, Construction Manual, dated 1955.

(6) Seed, H. G., "A Low-Cost Kneading Compactor," Institute of Transportation and Traffic Engineering, University of California, Information Circular No. 27.

(7) "An Evaluation of the Experimental California Soil Compaction Test Apparatus," Materials and Research Department Report, California Division of Highways, May 1966.

TABLE I

Reproducibility of Density Using the Big Mold Method

Test No.	Mold Density	Moisture Content	Density Count Ratio	Soil Type
5	101.0	30.5	0.75	Tuff
	103.5	30.2	0.75	
6	115.9	25.5	0.60	Fire Clay
	115.1	25.2	0.61	
7	147.7	9.8	0.43	Rocky Clay
	146.5	9.5	0.40	
	145.6	11.7	0.43	
	146.6	11.2	0.40	
18	137.6	17.6	BS 1.38 T 0.24	Clay
	137.6	17.9	BS 1.37 T 0.24	
20	133.8	17.5	BS 1.44 T 0.27	Clay
	134.1	17.2	BS 1.45 T 0.28	
	131.3	19.4	BS 1.45 T 0.28	
	132.5	19.1	BS 1.45 T 0.28	
21	131.4	15.4	BS 1.44 T 0.27	Sandy Clay
	130.6	14.9	BS 1.43 T 0.28	
22	128.0	19.7	BS 1.46 T 0.29	Clay
	127.5	19.4	BS 1.46 T 0.29	
26	138.3	7.9	BS 1.43 T 0.25	Rocky Clay
	135.2	7.8	BS 1.48 T 0.25	
30	130.9	20.2	BS 1.45 T 0.28	Clayey Shale
	129.7	20.1	BS 1.46 T 0.30	

Test No.	Mold Density	Moisture Content	Density Count Ratio	Soil Type
31	132.8	16.8	BS 1.43 T 0.27	Rocky Clay
	133.3	17.1	BS 1.42 T 0.28	
32	135.6	11.2	BS 1.47 T 0.26	Rocky Clay
	136.8	11.8	BS 1.43 T 0.26	
34	144.0	11.6	BS 1.36 T 0.25	Clay & Cobbles
	141.3	11.5	BS 1.39 T 0.25	
36	149.6	5.6	BS 1.36 T 0.21	Agg. Subb.
	145.9	5.3	BS 1.37 T 0.23	
37	150.9	6.5	BS 1.39 T 0.22	Agg. Base
	147.2	6.0	BS 1.38 T 0.23	

TABLE II

Variation in Count With Respect to Type of Shield
Used With the Transmission Detector Rod in the Big Mold

Sample No.	Soil Type	Wet Density	Shield Type: U Shaped	U+60°	U+120°	No Shield
65-3074	Sand	121	6840	6970	7760	6920
65-3454	Clay	128	5990	6250	6360	
		134	5570	5590	5840	
		131	5810	5980	6150	
		133	5780	5920	6140	
65-3604	Clay & Sand	133	5610	5810	6060	
65-3603	Clay	121	6890	7150	7320	
65-4019	Rocky Clay	138	5210	5380	5550	
65-4033	Sandy Clay Gravel	144	4650	4880	4960	
	Clay	111	8155	8325	8575	8470
		113	7125	7370	7590	7295
		122	6365	6615	6780	6420
		124	6065	6320	6515	6140
		122	6725	6865	7100	6830
		125	6065	6285	6435	6165
		123	6655	6830	7050	6620
		122	6250	6565	6740	6375

TABLE III

Counts at Various Core Lengths - Phase II

Core Density		Core Length in Inches							
		14.0	13.5	13.0	12.5	12.0	11.5	11.0	10.5
124	M	1990	1930	1770	1490	1300	1030	745	520
	BS	30580	30540	30330	30720	30450	30320	30230	30130
	T	6400	6430	6450	6140	6420	6220	6290	6250
110	M	1220	1110	1070	980	840	740	550	430
	BS	32280	32220	32120	32060	32350	32300	32560	32590
	T	7570	7550	7760	8360	8370	8410	8400	8500

M - Moisture, BS - Backscatter, T - Transmission

Source to detector distances (Horizontal)

Moisture 3.0
Backscatter 7.0
Transmission - 11.0

Counts from Varying Probe Positions on Core - Phase I

Core Density	Centered	Moving Source Toward End of Mold in Inches 0.5	1.0	1.5	2.0	2.5	3.0
110	10530	10752	11180	11320	11420	10560	8960

	Centered	Moving Detector Toward End of Mold in Inches 0.5	1.0	1.5	2.0	2.5
110	10550	10450	8820	7430	6050	5620

Core length = 11.0'

Source to detector length = 8.0"

TABLE IV

Comparison of Calif. T. M. 216-F
and the Big Mold-Nuclear Gage Method
With Respect to Acceptance of Earthwork

TYPE OF TEST	PROJECT & SOIL	SITES A	B	C	D	E	F	REMARKS
Calif. Impact	9		95			93		90% Required
Big Mold	Silty Sand							
Backscatter		R	A	A	A	A	A	Accept Area
Calif. Impact	10	95			91			95% Required
Big Mold	Rocky Clay							
Backscatter		R	R	R	R	R	R	Rework
Calif. Impact	11	89		91				90% Required
Big Mold	Silty Clay							
Backscatter		R	R	R	R		R	Rework
Calif. Impact	12			88			91	90% Required
Big Mold	Clayey							
Backscatter	Silty Sand	R	R	R	R	R	R	Rework
Calif. Impact	13	82		82				90% Required
Big Mold	Silty Sand							
Backscatter		R	R	R	R	R	R	Rework
Calif. Impact	14	85				84		90% Required
Big Mold	Clayey Silt							
Backscatter		R	R	R	R	R	R	Rework
Calif. Impact	15	86			89			90% Required
Big Mold	Clay							
Backscatter		R	R	R	R	R	R	Rework
Calif. Impact	16				90		81	90% Required
Big Mold	Silty Sand							
Backscatter		R	R	R	R	R	R	Rework
Calif. Impact	17		88					90% Required
Big Mold	Sand							
6" Transmission		R	R	R	R	R	R	Rework
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	18			82			91	90% Required
Big Mold	Clay							
6" Transmission		R	R	R	R	R	R	Rework
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	19		86				89	90% Required
Big Mold	Decomposed							
6" Transmission	Granite	R	R	R	A	R	R	Rework
10" Transmission		R	R	R	R	R	R	"

TABLE IV (Contd.)

TYPE OF TEST	PROJECT & SOIL	A	B	SITES C	D	E	F	REMARKS
Calif. Impact	20			95			100	95% Required
Big Mold	Clay							
Backscatter	Subgrade	R	A	R	R	A	R	Rework
6" Transmission		A	R	R	R	A	A	Rework
10" Transmission		R	R	A	A	A	A	Accept Area
Calif. Impact	21			87	92			90% Required
Big Mold	Sandy Clay							
Backscatter		R	R	R	R	R	R	Rework Area
6" Transmission		R	R	R	R	R	R	" "
10" Transmission		R	R	R	R	R	R	" "
Calif. Impact	22			94	93			90% Required
Big Mold	Clay							
Backscatter		R	R	A	R	A	R	Rework Area
6" Transmission		R	R	A	A	R	R	" "
10" Transmission		R	R	R	R	R	R	" "
Calif. Impact	23	85			86			95% Required
Big Mold	Sand							
Backscatter	Str. Bkfl.	R	R	R	A	R	R	Rework
6" Transmission		R	R	R	R	R	R	"
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	25	93					89	90% Required
Big Mold	Silt							
Backscatter		A	A	A	A	A	A	Accept Area
6" Transmission		A	R	A	R	A	R	Rework
10" Transmission		A	R	A	R	R	R	Rework Area
Calif. Impact	26	93					91	90% Required
Big Mold	Rocky Clay							
Backscatter		R	R	R	R	R	R	Rework
6" Transmission		R	R	R	R	R	R	"
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	27	89					96	90% Required
Big Mold	Rocky Clay							
Backscatter		R	R	R	R	R	R	Rework
6" Transmission		R	R	R	R	R	R	"
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	28	92					92	95% Required
Big Mold	Rocky Sandy							
Backscatter	Clay	R	A	R	R	R	A	Rework
6" Transmission	Subgrade	R	R	R	R	R	A	"
10" Transmission		A	A	R	R	R	A	"

TABLE IV (Contd.)

TYPE OF TEST	PROJECT & SOIL	SITES A	B	C	D	E	F	REMARKS
Calif. Impact	29	86					86	90% Required
Big Mold	Tuff							
Backscatter		R	R	A	R	A	A	Rework
6" Transmission		R	R	R	R	R	R	"
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	30	90				90		90% Required
Big Mold	Clay &							
Backscatter	Shale	A	R	A	A	R	R	Rework
6" Transmission		A	R	R	A	R	R	"
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	31	95				94		90% Required
Big Mold	Rocky Clay							
Backscatter		R	R	R	R	A	R	Rework
6" Transmission		A	R	R	A	A	A	Accept Borderline
10" Transmission		A	R	A	A	A	R	Accept
Calif. Impact	32	85			84			90% Required
Big Mold	Rocky Clay							
Backscatter		R	R	R	R	R	R	Rework
6" Transmission		R	R	R	R	R	R	"
10" Transmission		R	R	R	R	R	R	"
Calif. Impact	33	99					91	90% Required
Big Mold	Sandy Clay							
Backscatter	& Gravel	R	R	R	R	R	R	Rework
6" Transmission		R	R	R	R	R	R	"
10" Transmission		A	R	A	R	R	R	"
Calif. Impact	34			91			92	90% Required
Big Mold	Clay &							
Backscatter	Cobbles	R	R	R	R	R	R	Rework
6" Transmission		R	R	R	R	A	R	"
10" Transmission		R	A	R	A	A	R	"
Calif. Impact	35	96			98			95% Required
Big Mold	Sand & Agg.							
Backscatter	A. S.	R	A	A	A	R	A	Accept
6" Transmission		R	A	R	A	R	R	Rework
10" Transmission		R	R	R	R	R	A	"
Calif. Impact	36	95					97	95% Required
Big Mold	Sand & Agg.							
Backscatter	A. S.	R	R	R	R	R	R	Rework
6" Transmission		R	R	R	R	R	A	"
10" Transmission		A	R	A	R	R	A	"

TABLE IV (Contd.)

TYPE OF TEST	PROJECT & SOIL	SITES A	B	C	D	E	F	REMARKS
Calif. Impact	37	109					103	95% Required
Big Mold	Sand & Agg.							
Backscatter	A. B.	A	A	A	R	R	A	Accept
6" Transmission		A	A	A	A	R	A	"
10" Transmission		A	A	A	A	R	A	"

TABLE V

Summary of Project Data on Materials
Requiring 90% Relative Compaction

MATERIAL		LABORATORY TEST EVALUATION MAXIMUM WET DENSITY			FIELD EVALUATION IMPACT COMP. & SAND VOL.		FIELD EVALUATION BIG MOLD & NUCLEAR TRANSMISSION	
No. (1)	Type (2)	Impact Comp. p.c.f. (3)	Big Mold p.c.f. (4)	Big Mold Impact % (5)	Relative Compaction Obtained (6)	Area Acceptance (7)	% of Tests Accepted (6 Tests) (8)	Area Acceptance (9)
11	Silty Clay	138	136	99	89-91	Marginal	0*	Reject
12	Clay, Silt & Sand	136	134	99	88-91	"	0*	"
14	Clayey-Silt	138	131	95	85-84	Reject	0*	"
15	Clay	142	137	97	86-89	"	0*	"
18	Clay	143	138	97	82-91	"	0	"
21	Sandy Clay	142	134	95	87-92	Marginal	0	"
22	Clay	128	128	100	94-93	Accept	0	"
25	Silt	131	124	95	93-89	Marginal	33	"
26	Rocky Clay	148	143	97	93-91	Accept	0	"
27	Rocky Clay	147	143	97	89-96	Marginal	0	"
29	Tuff	107	102	95	86-86	Reject	0	"
30	Clay & Shale	136	131	96	90-90	Accept	0	"
31	Rocky Clay	139	133	96	95-94	"	67	Accept
32	Rocky Clay	143	138	97	85-84	Reject	0	Reject
33	Sandy Clay	150	150	100	99-91	Accept	33	"
34	Clay & Cobbles	153	144	94	91-92	"	50	"
9	Silty Sand	130	128	99	95-93	"	83*	Accept
13	Silty Sand	140	134	96	82-82	Reject	0*	Reject
16	Silty Sand	137	131	96	90-81	"	0*	"
17	Sand	126	121	96	88	"	0	"
19	Decomposed Gran.	126	119	95	86-88	"	0	"
		AVERAGE		97				

*By Backscatter only.

TABLE VI

Summary of Project Data on Materials
Requiring 95% Relative Compaction

MATERIAL		LABORATORY TEST EVALUATION MAXIMUM WET DENSITY			FIELD EVALUATION			
					IMPACT COMP. & SAND VOL.		BIG MOLD & NUCLEAR TRANSMISSION	
No. (1)	Type (2)	Impact Comp. p.c.f. (3)	Big Mold p.c.f. (4)	Big Mold Impact % (5)	Relative Compaction Obtained (6)	Area Acceptance (7)	% of Tests Accepted (6 Tests) (8)	Area Acceptance (9)
35	Agg. Subbase	157	145	93	96-98	Accept	17	Reject
36	" "	158	152	96	95-97	"	50	"
37	Agg. Base	154	155	101	109-103	"	83	Accept
23	Sand (a)	122	111	91	85-86	Reject	0	Reject
10	Rocky Clay (b)	154	148	96	95-91	Reject	0	Reject
20	Clay (b)	138	134	97	95-100	Accept	67	Accept
28	Rocky-Sandy Clay (b)	135	128	95	92-92	Reject	50	Reject
		Average		96				

(a) Structure Backfill
(b) Subgrade

Figure 1

DENSITY CALIBRATION CURVES

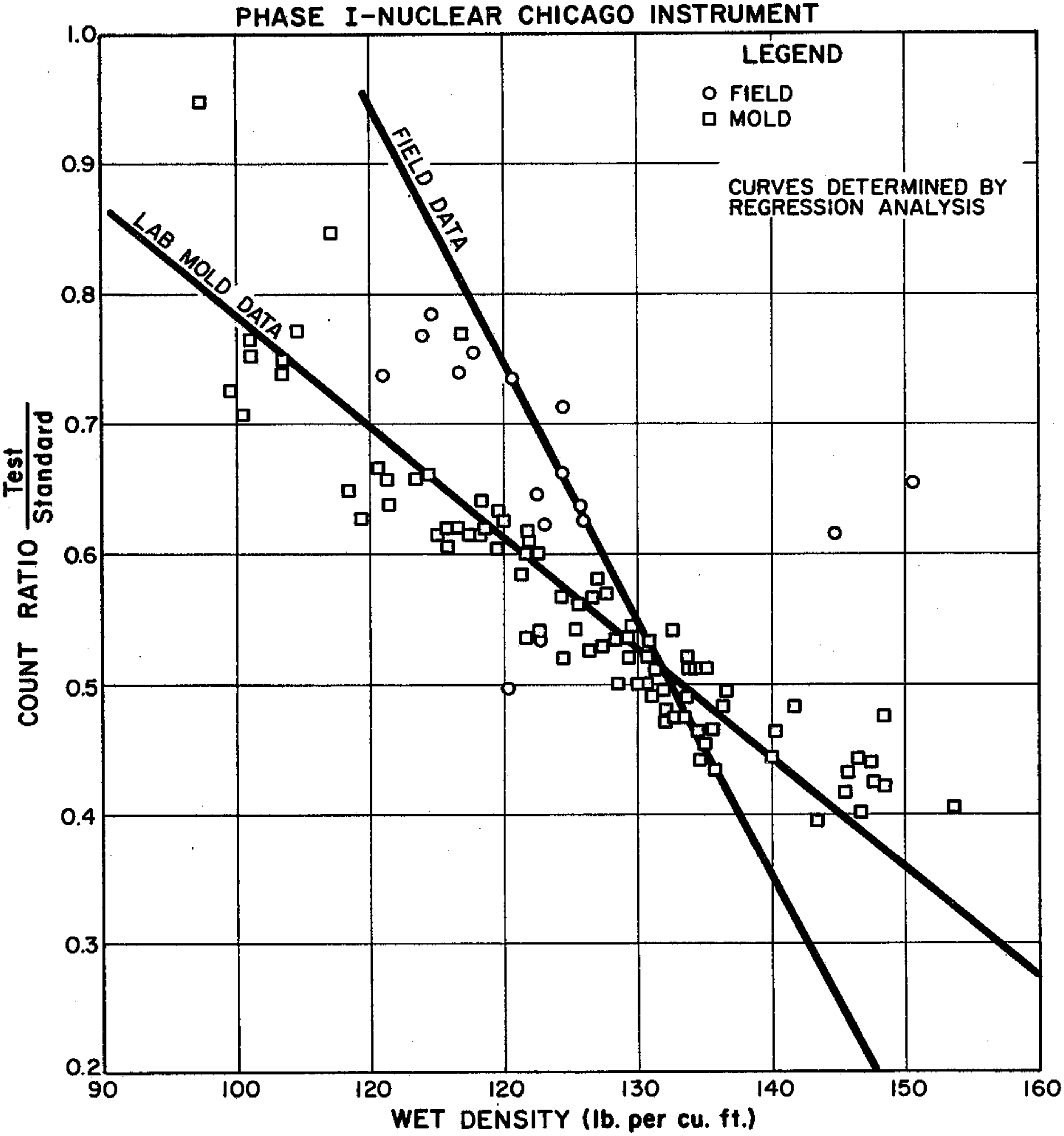


Figure 2

BACKSCATTER DENSITY CALIBRATION

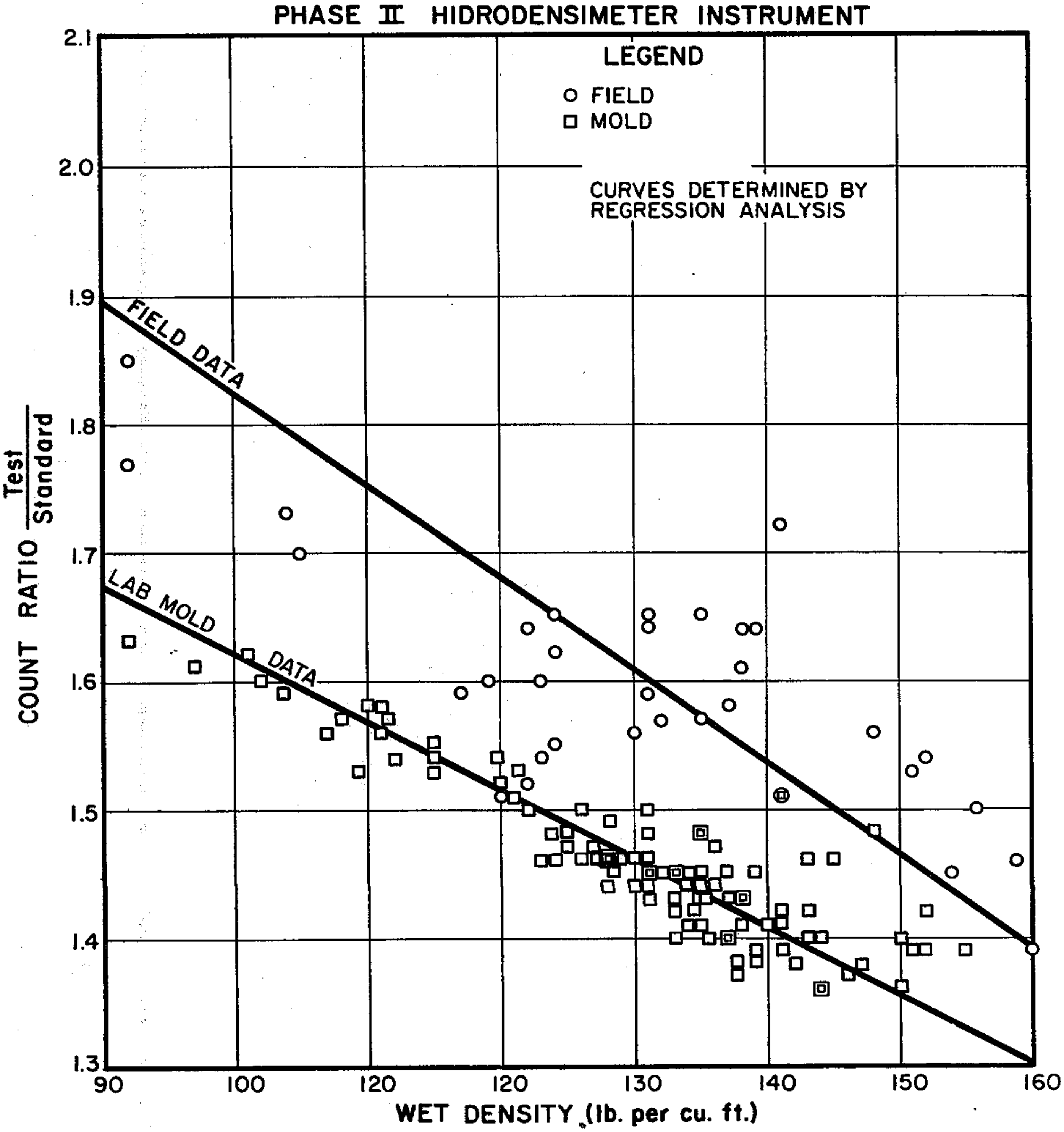


Figure 3

TRANSMISSION DENSITY CALIBRATION

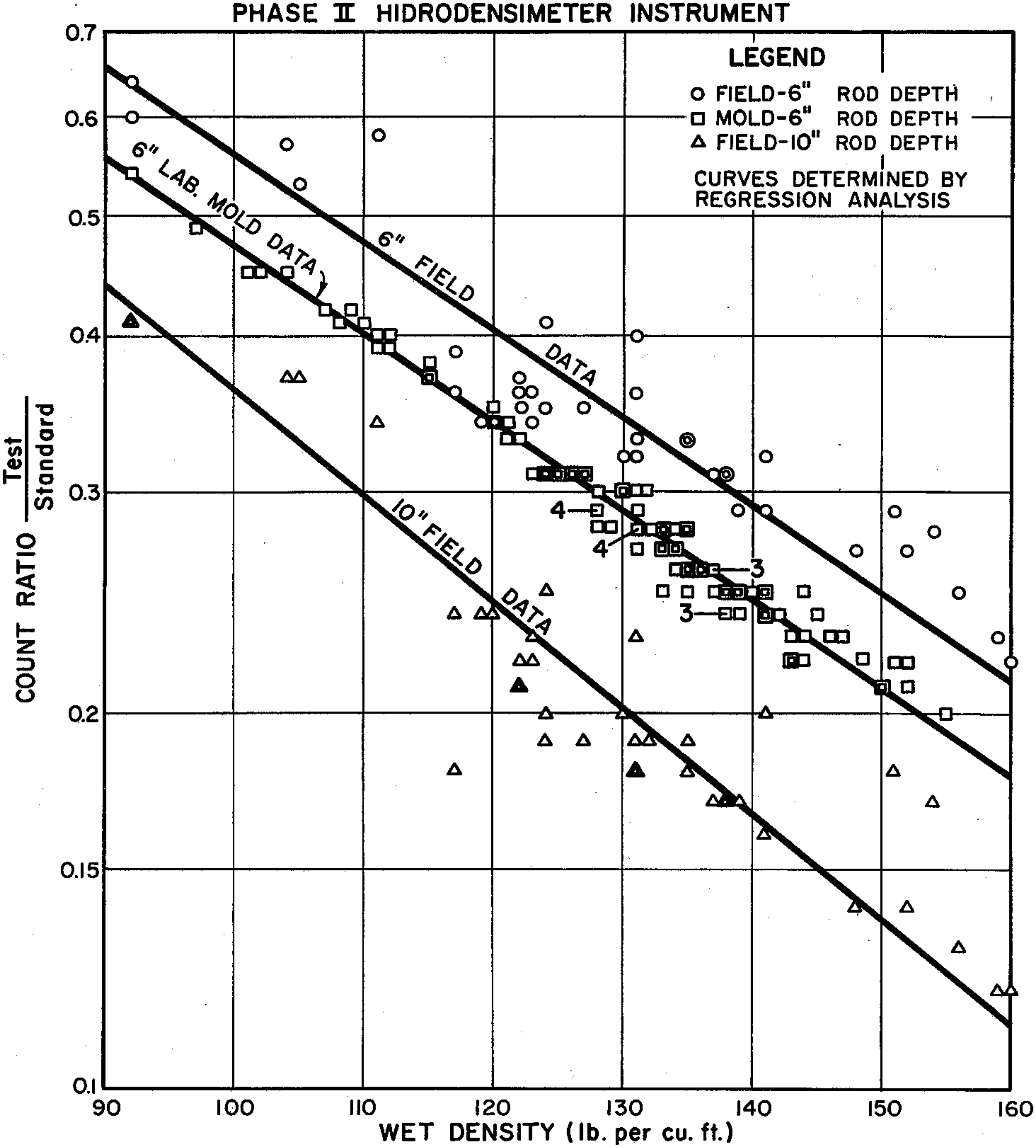


Figure 4

MOISTURE CALIBRATION

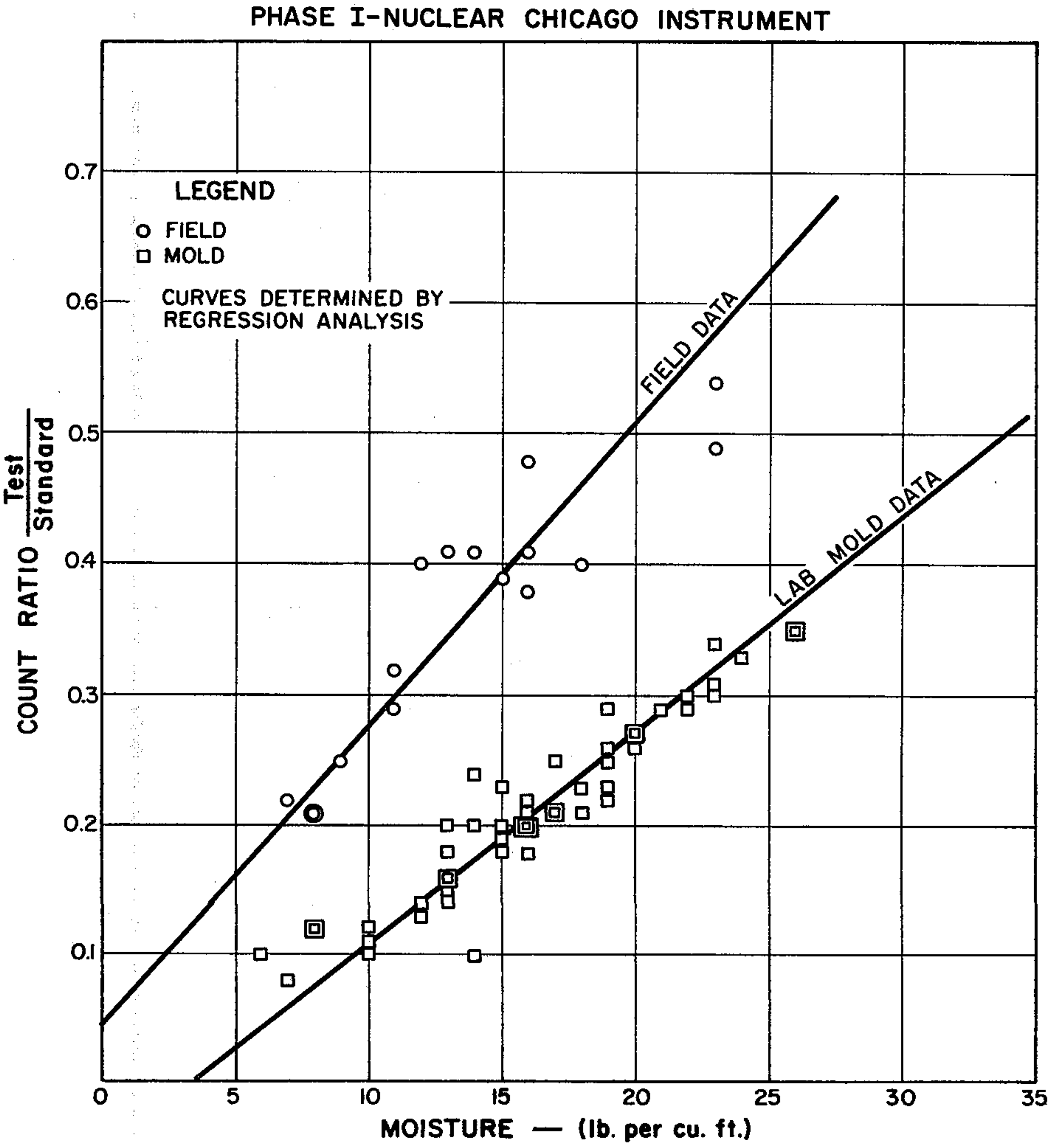


Figure 5

MOISTURE CALIBRATION

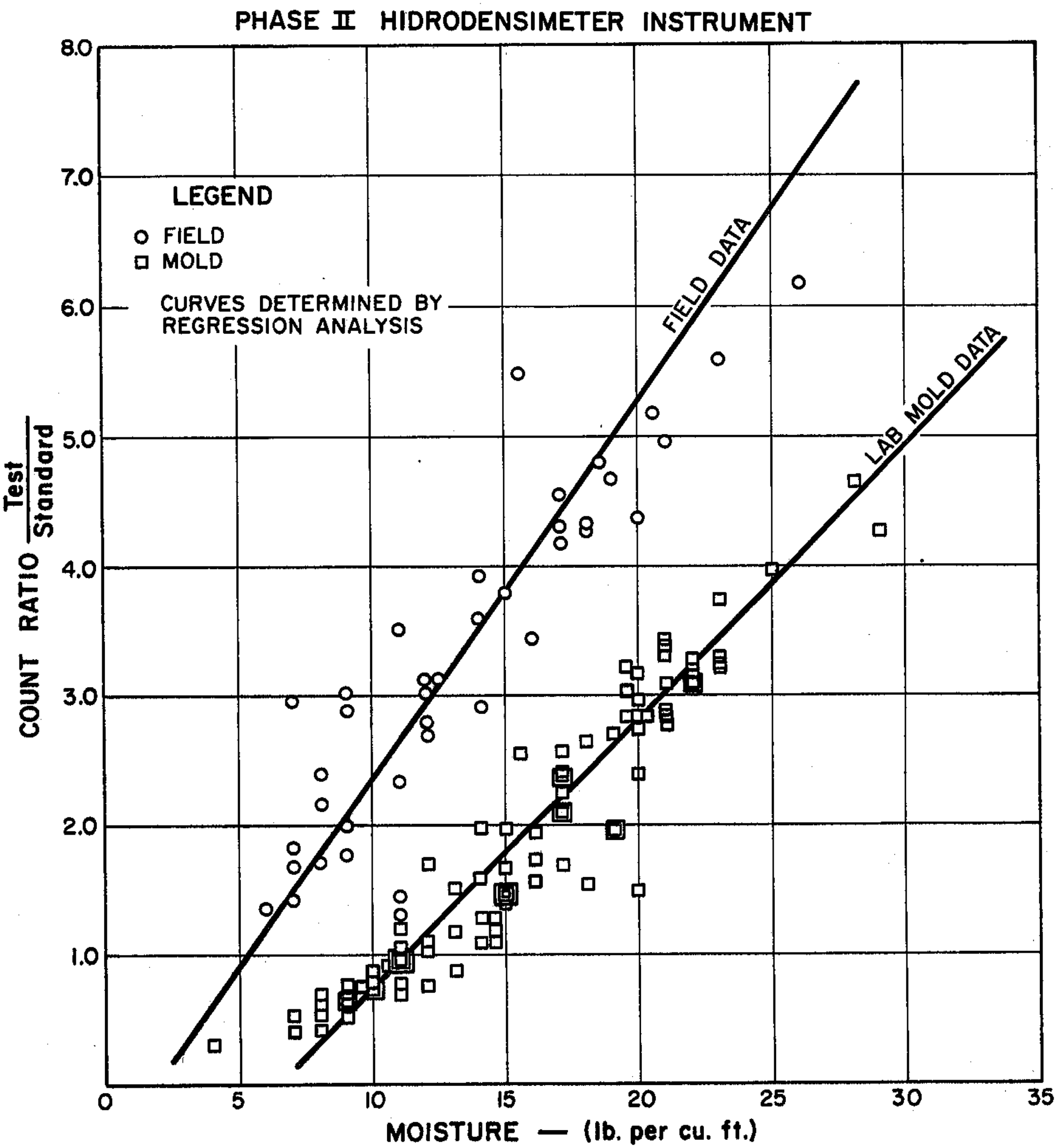
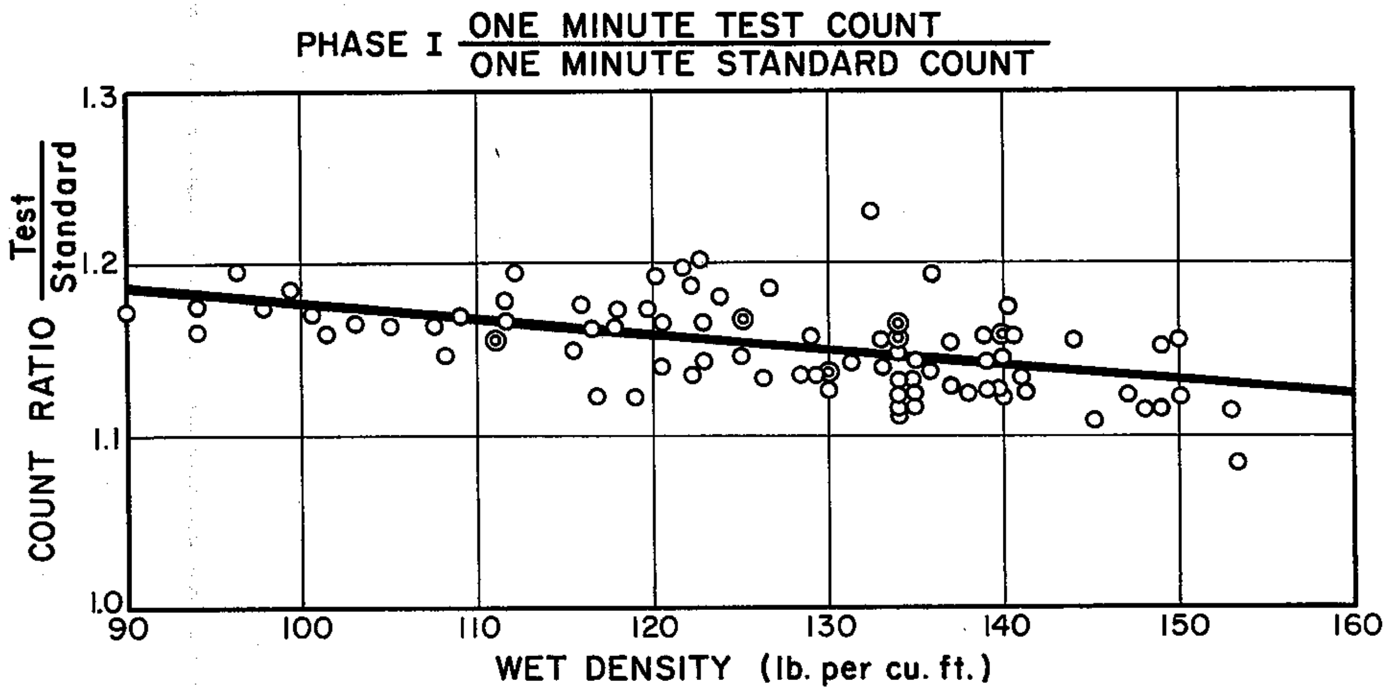


Figure 6

CALIFORNIA MOISTURE DENSITY APPARATUS
DENSITY CALIBRATION CURVES



NOTE: CURVES DETERMINED BY REGRESSION ANALYSIS

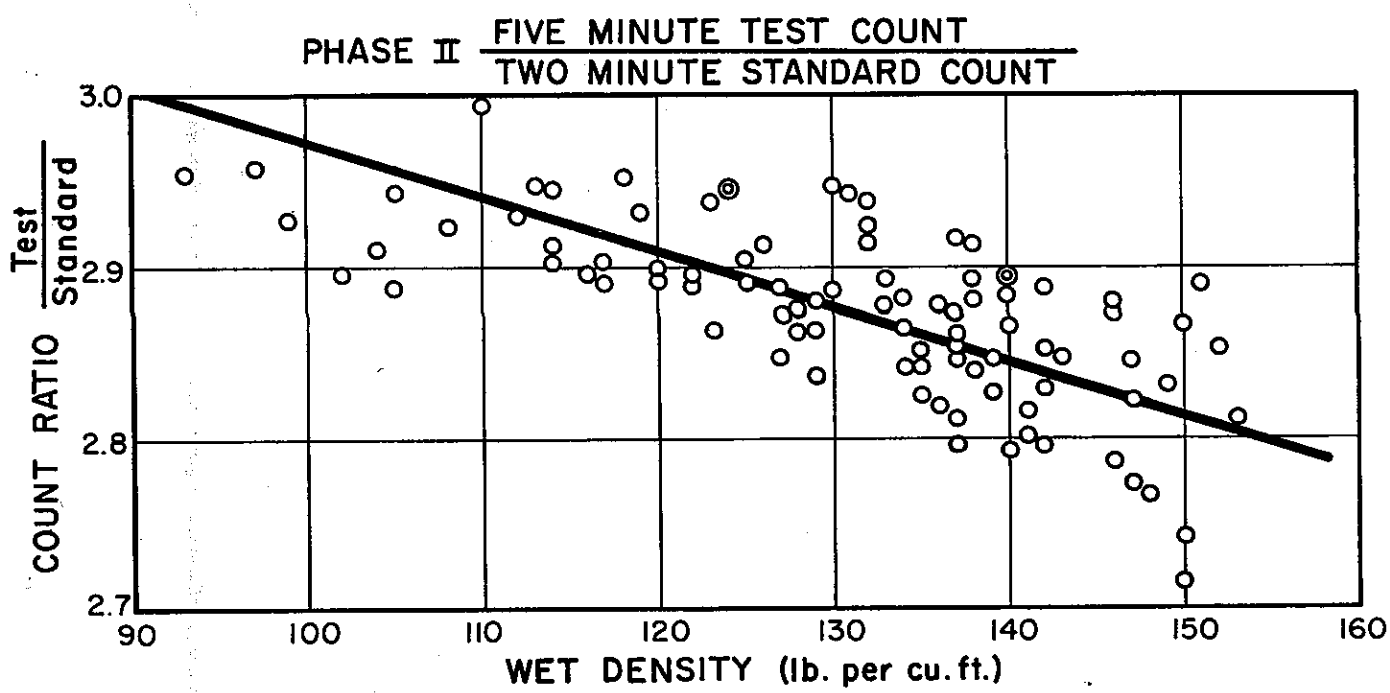
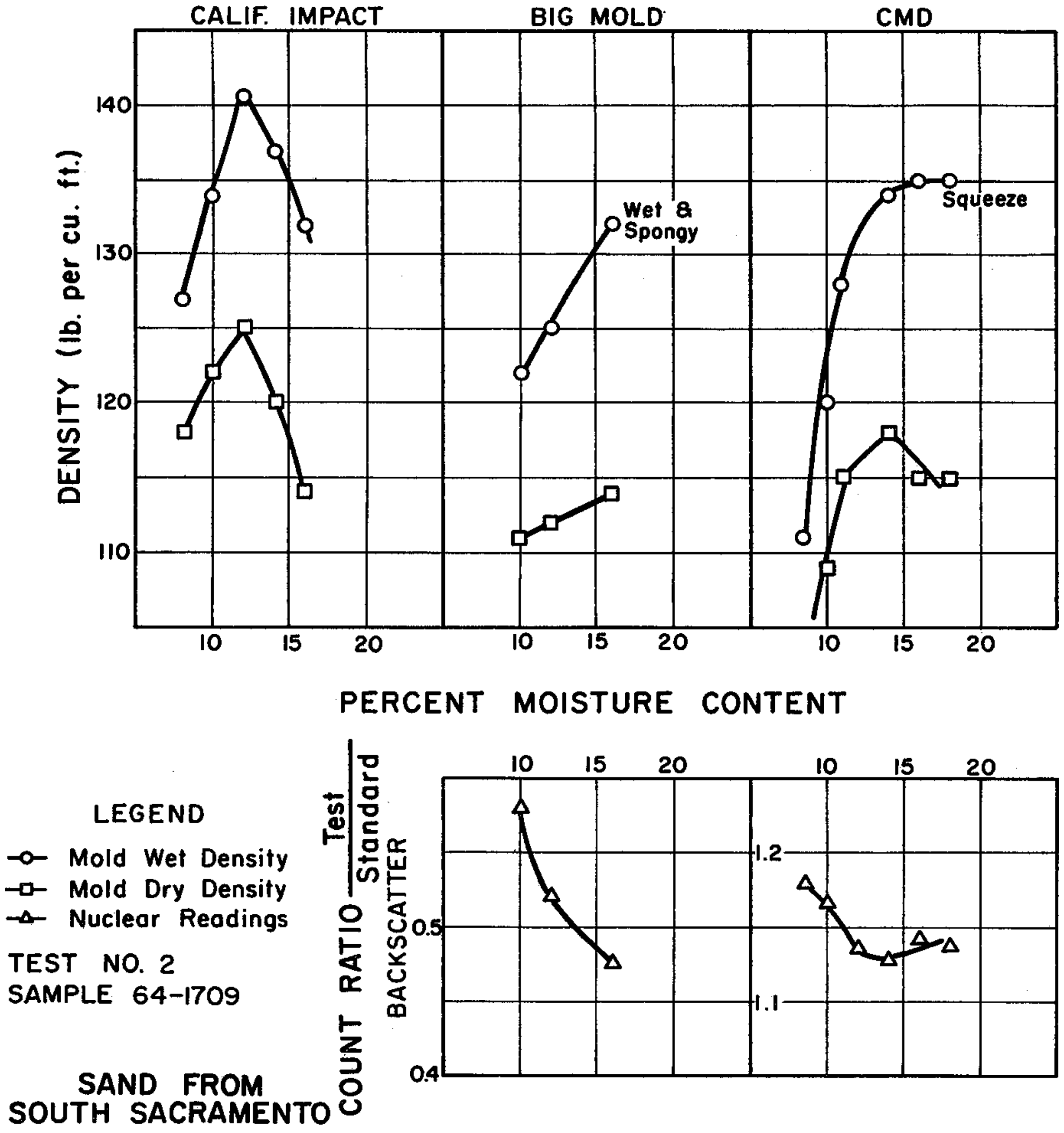


Figure 7

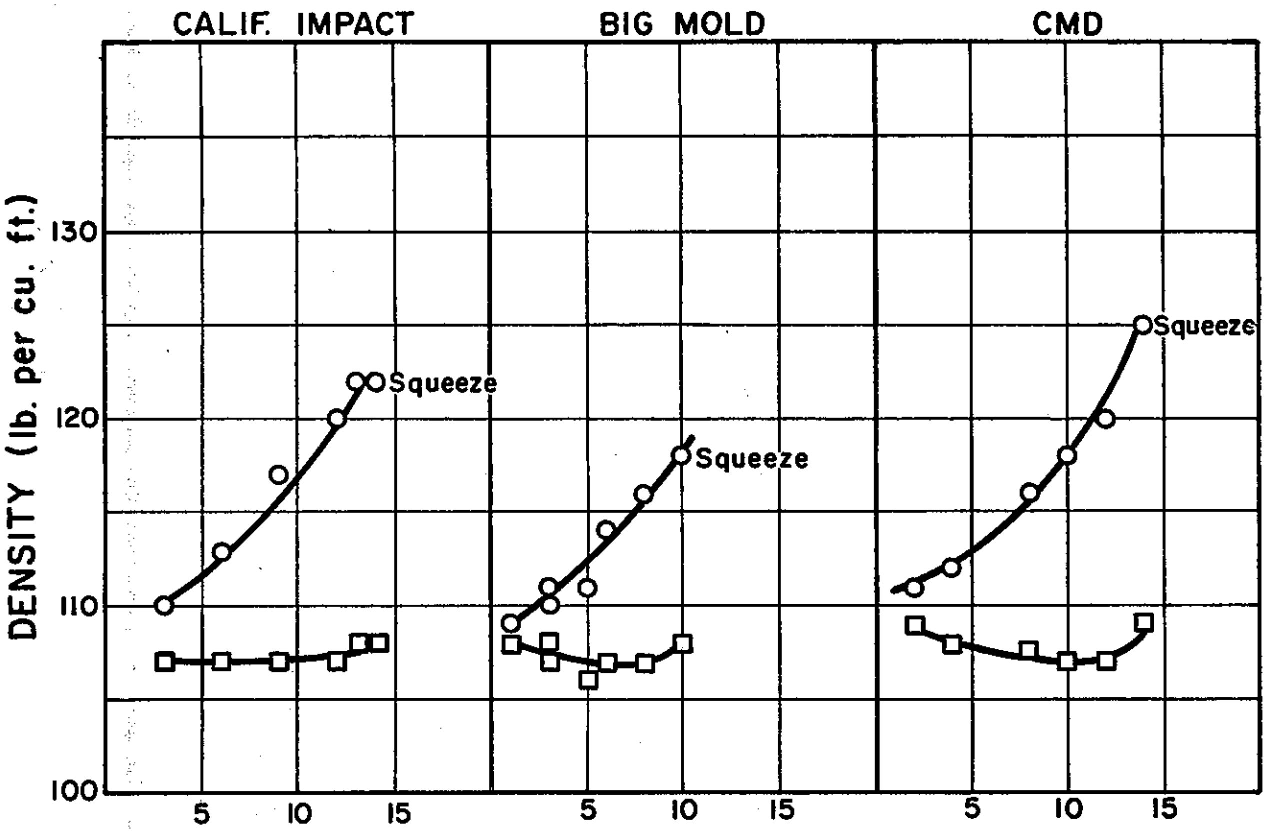
COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

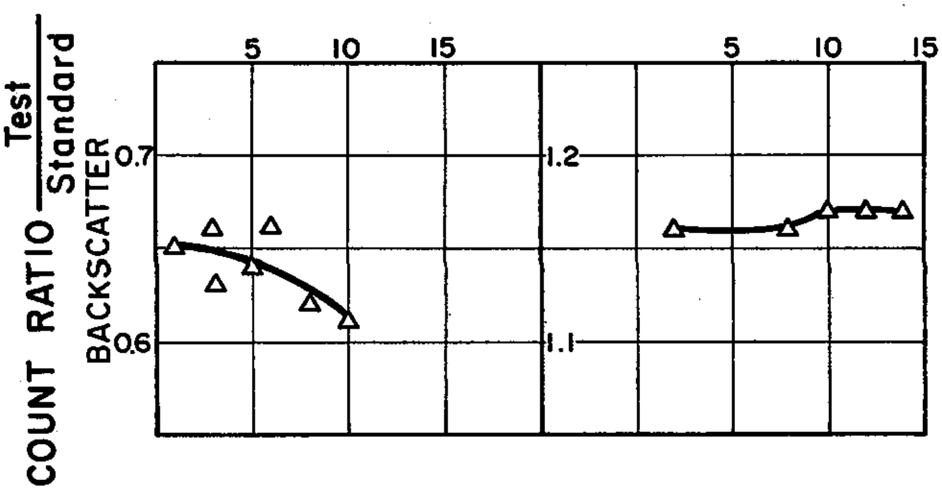


INSTRUMENT: NUCLEAR – CHICAGO

Figure 8

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS





LEGEND
- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

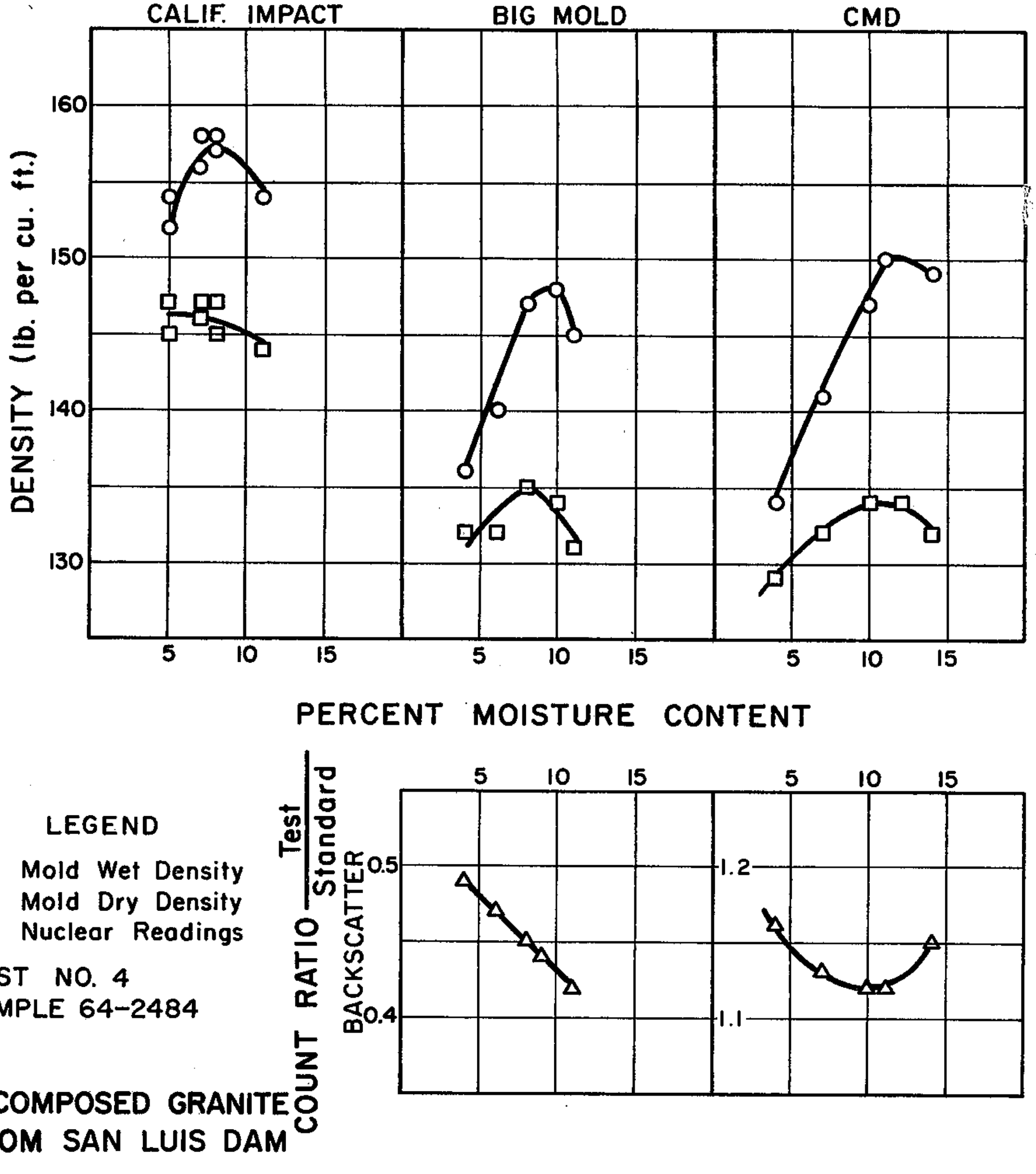
TEST NO. 3
SAMPLE 64-3694

SAND FROM MONTEREY

INSTRUMENT: NUCLEAR – CHICAGO

Figure 9

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

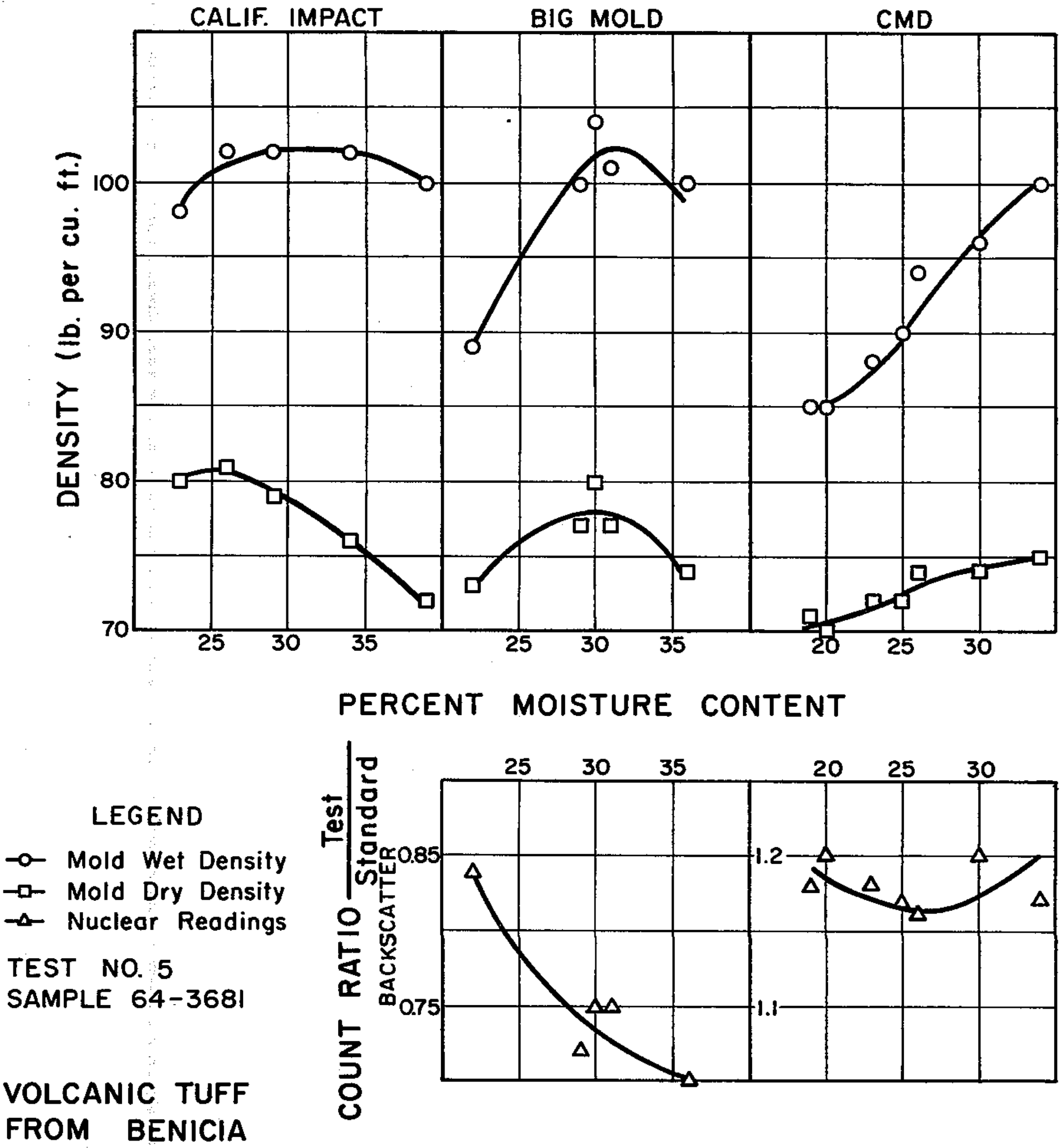
TEST NO. 4
SAMPLE 64-2484

DECOMPOSED GRANITE FROM SAN LUIS DAM

INSTRUMENT: NUCLEAR - CHICAGO

Figure 10

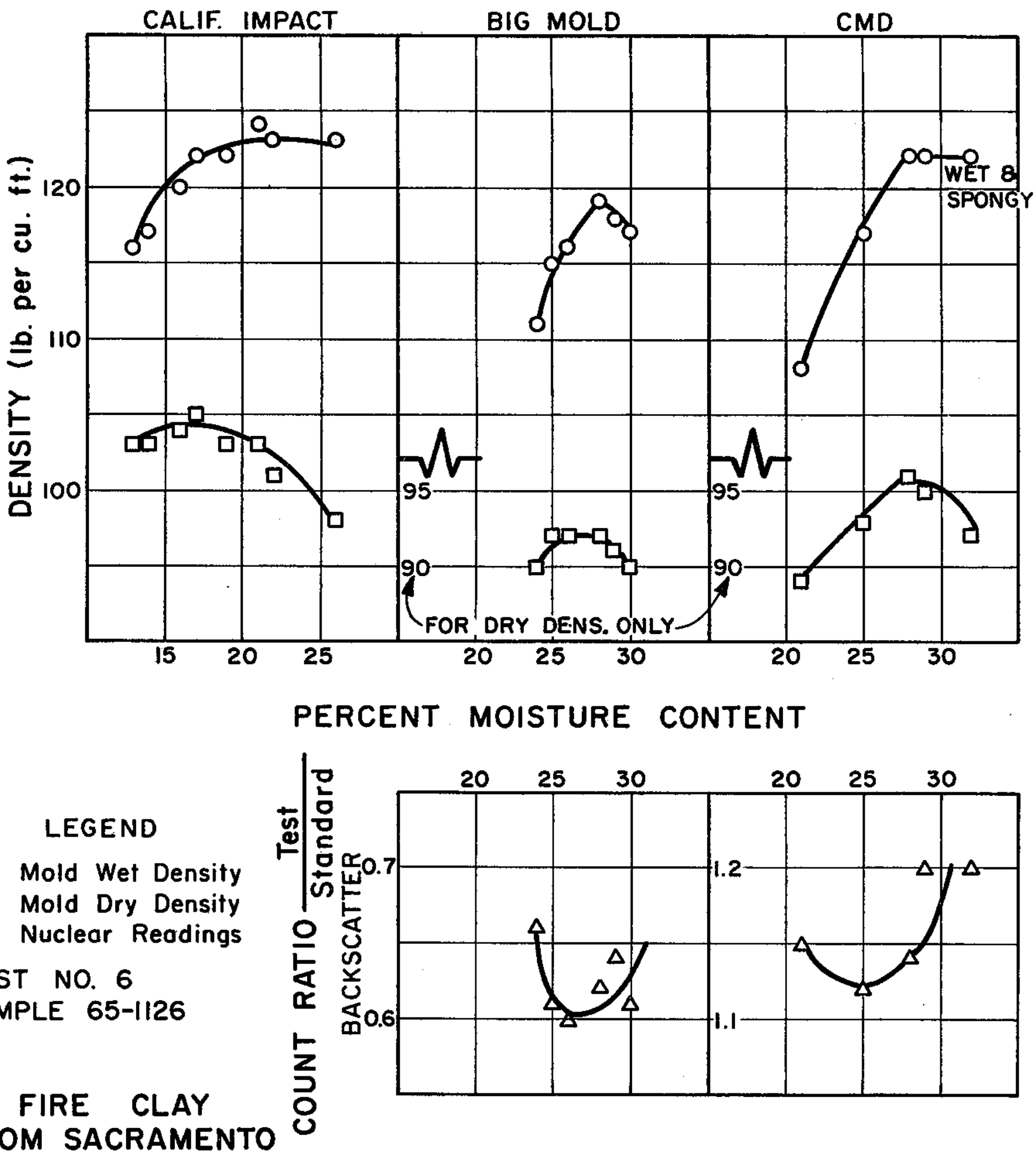
COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



INSTRUMENT: NUCLEAR – CHICAGO

Figure 11

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- -o- Mold Wet Density
- -□- Mold Dry Density
- -△- Nuclear Readings

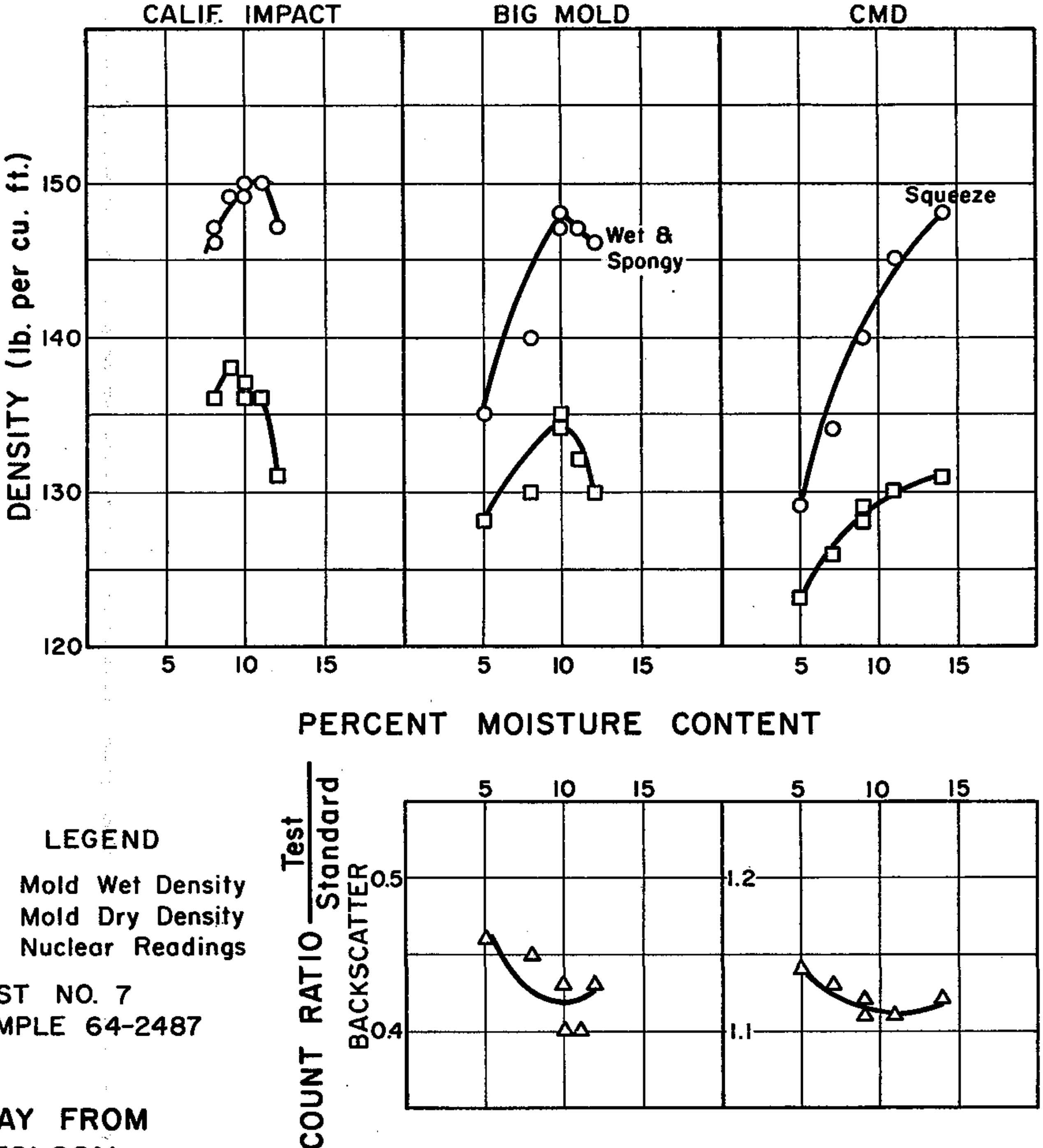
TEST NO. 6
SAMPLE 65-1126

FIRE CLAY
FROM SACRAMENTO

INSTRUMENT: NUCLEAR – CHICAGO

Figure 12

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

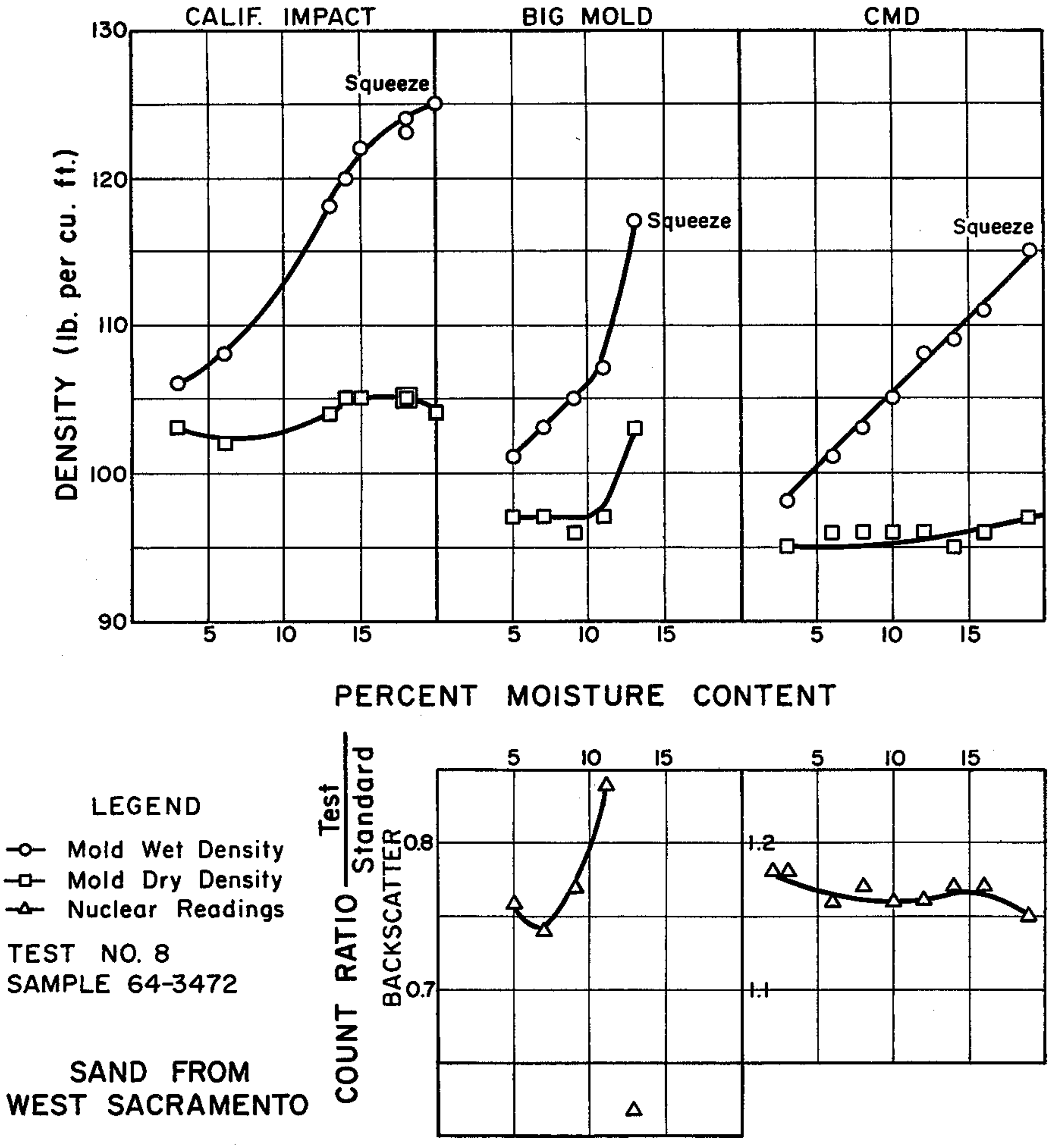
TEST NO. 7
SAMPLE 64-2487

CLAY FROM FOLSOM

INSTRUMENT: NUCLEAR – CHICAGO

Figure 13

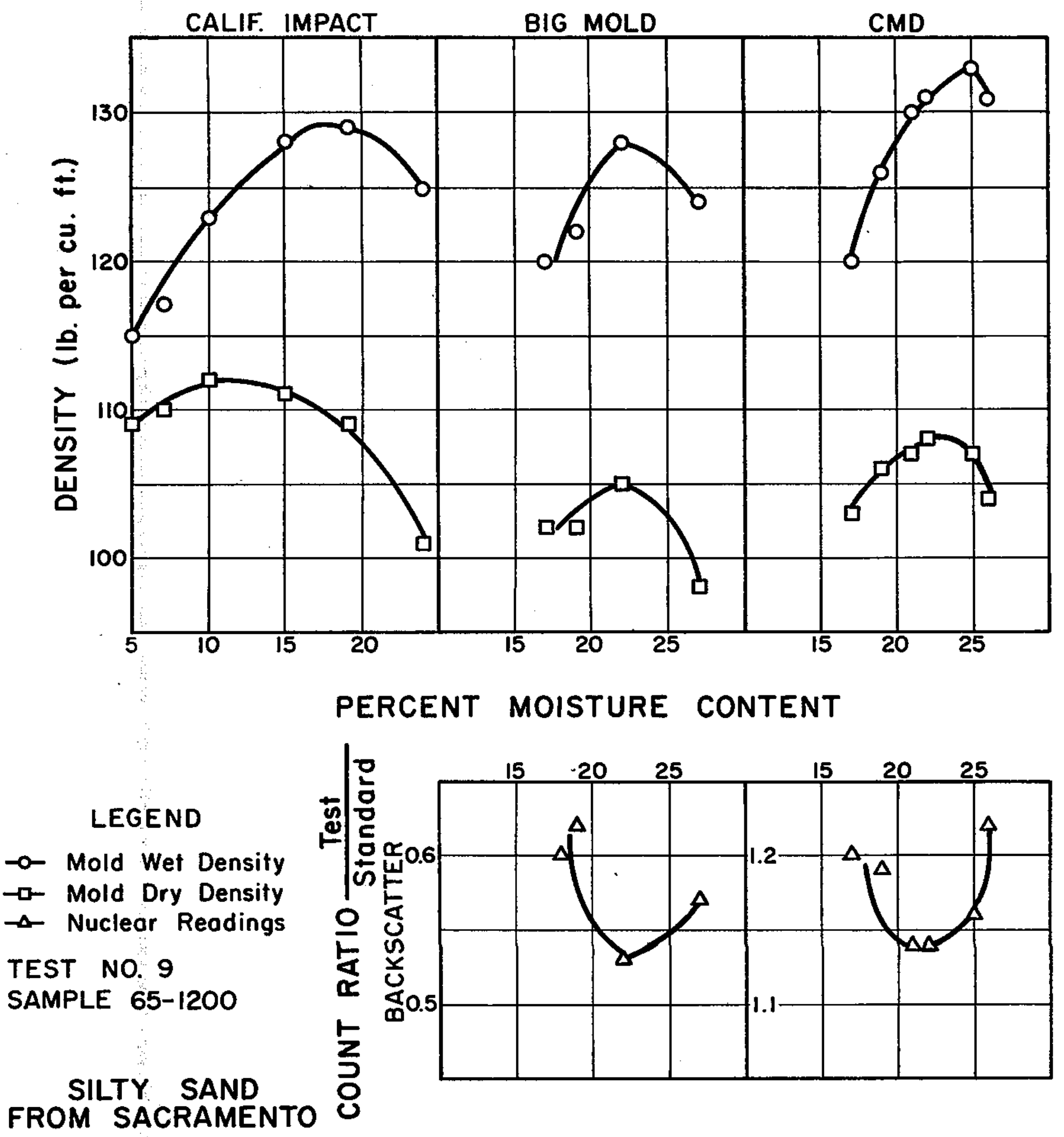
COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



INSTRUMENT: NUCLEAR – CHICAGO

Figure 14

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



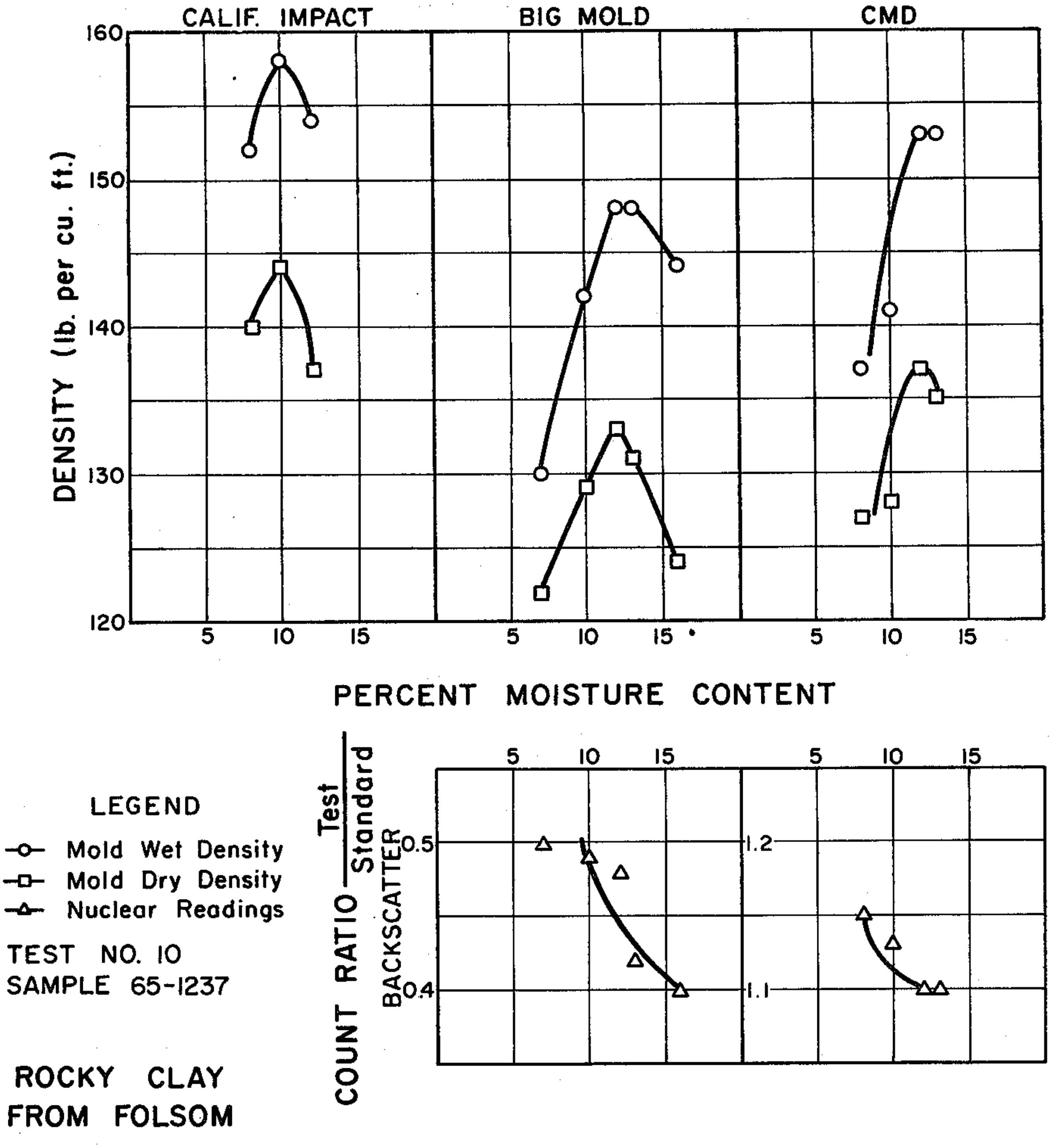
TEST NO. 9
SAMPLE 65-1200

SILTY SAND FROM SACRAMENTO

INSTRUMENT: NUCLEAR – CHICAGO

Figure 15

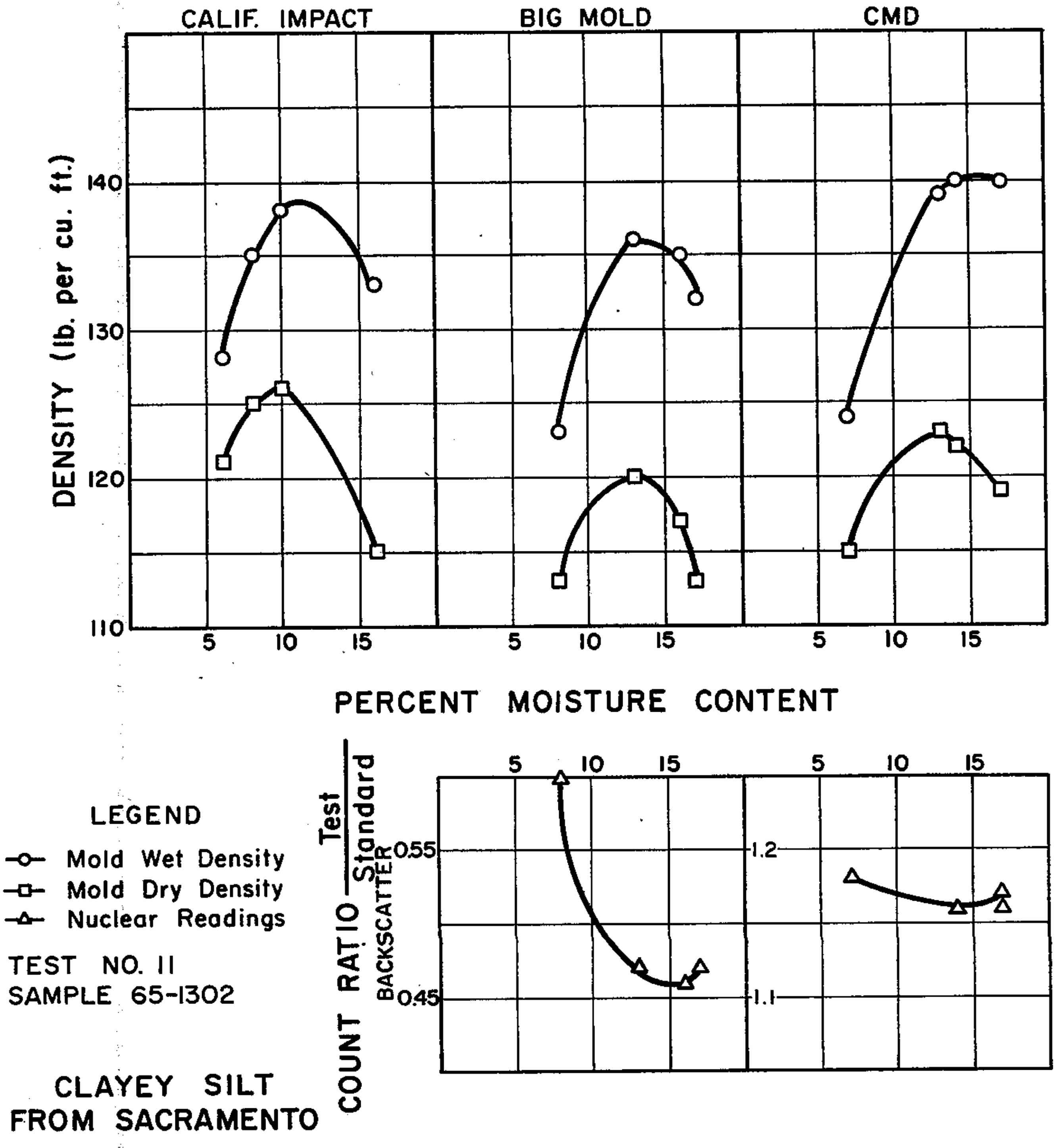
COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



INSTRUMENT: NUCLEAR – CHICAGO

Figure 16

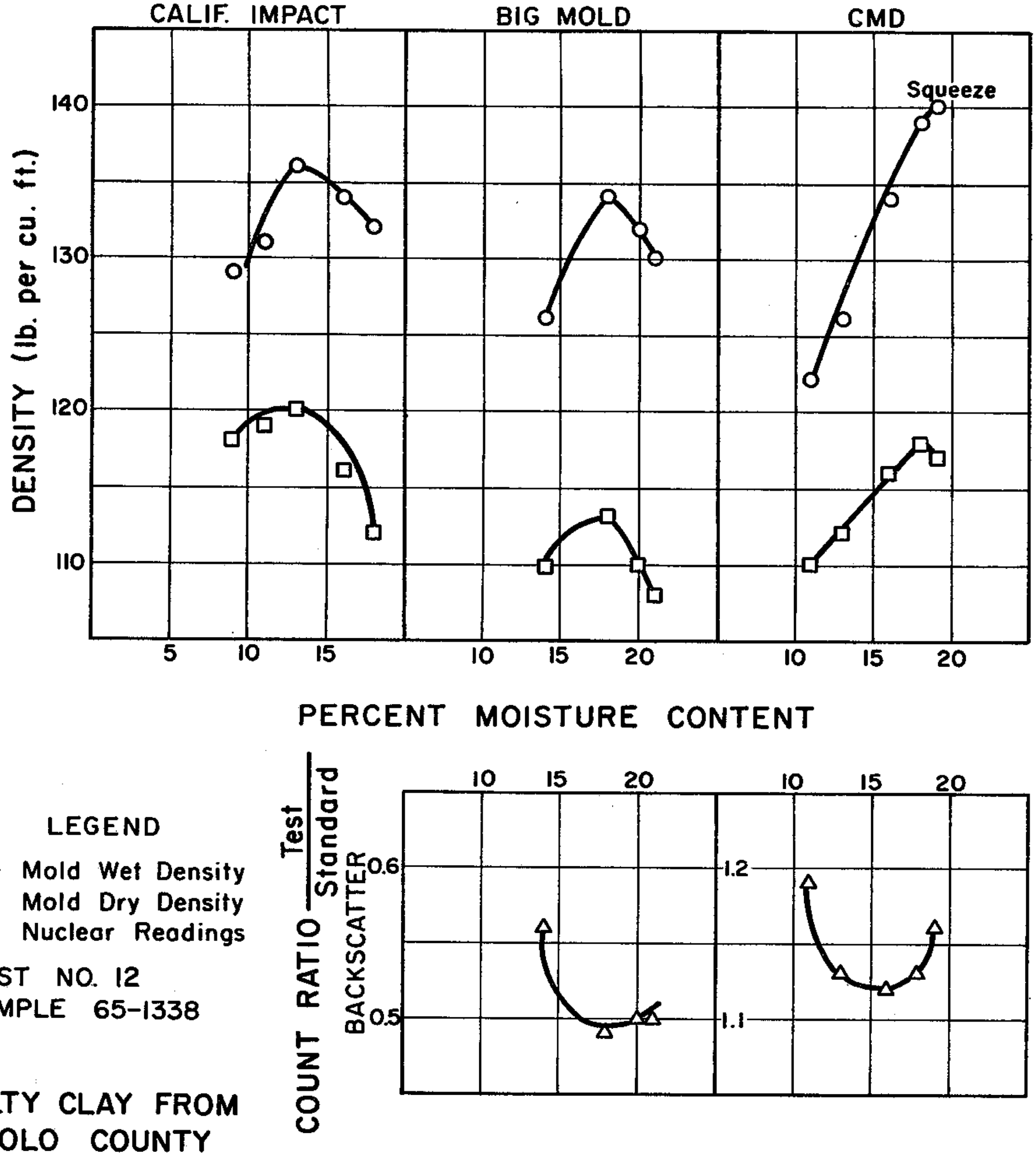
COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



INSTRUMENT: NUCLEAR – CHICAGO

Figure 17

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- -o- Mold Wet Density
- -□- Mold Dry Density
- -△- Nuclear Readings

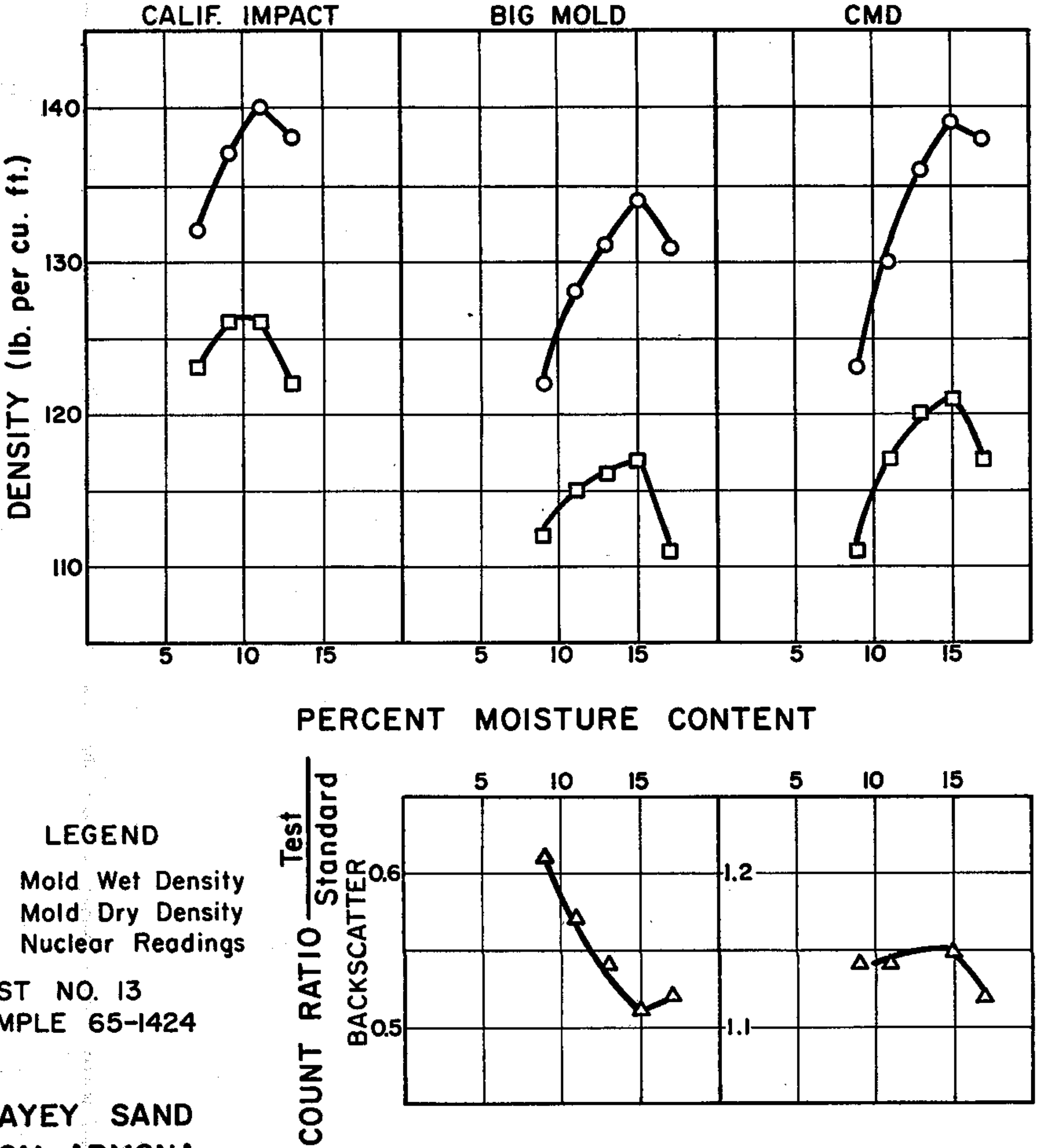
TEST NO. 12
SAMPLE 65-1338

SILTY CLAY FROM YOLO COUNTY

INSTRUMENT: NUCLEAR - CHICAGO

Figure 18

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

-○- Mold Wet Density
-□- Mold Dry Density
-△- Nuclear Readings

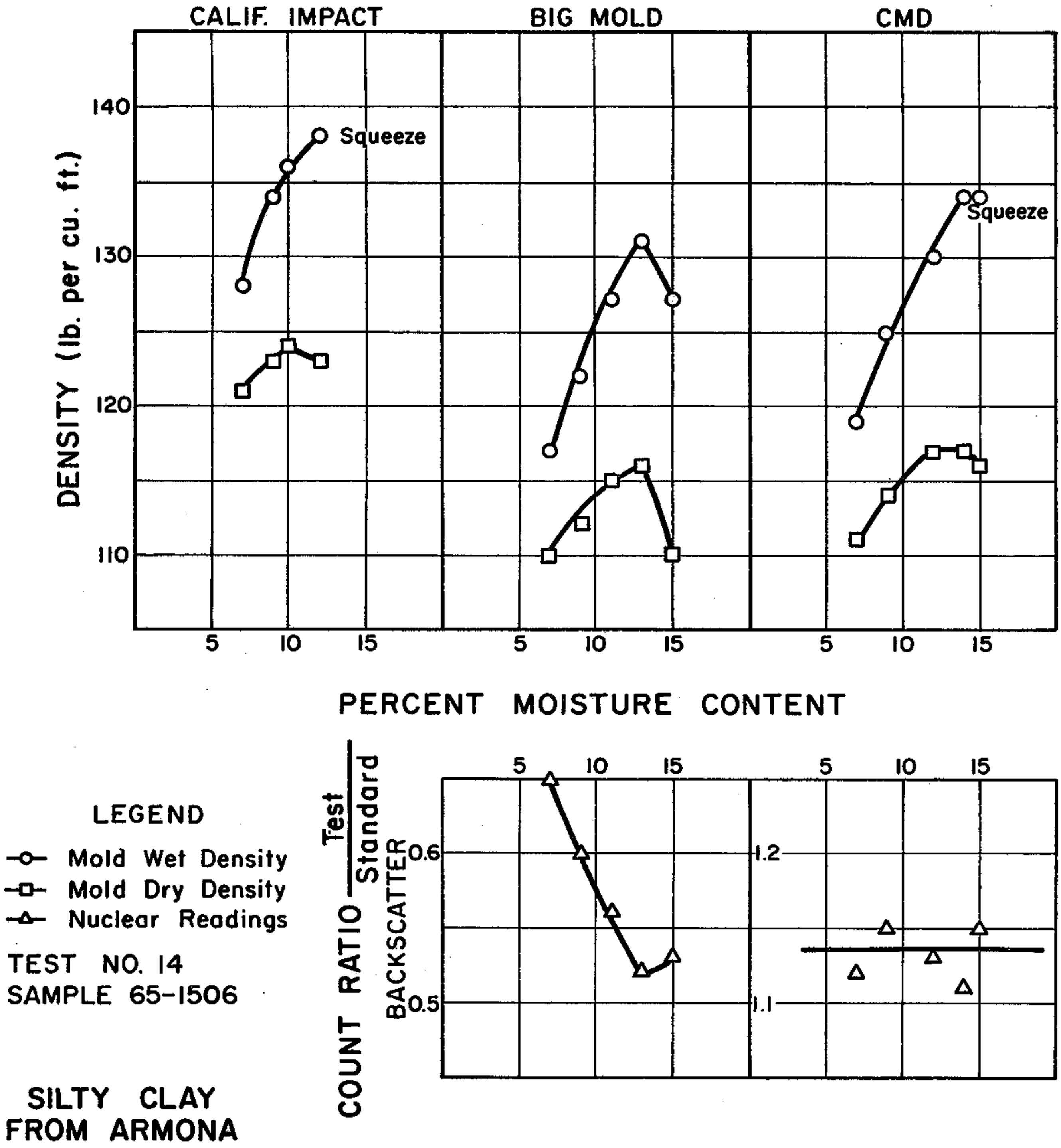
TEST NO. 13
SAMPLE 65-1424

CLAYEY SAND
FROM ARMONA

INSTRUMENT: NUCLEAR – CHICAGO

Figure 19

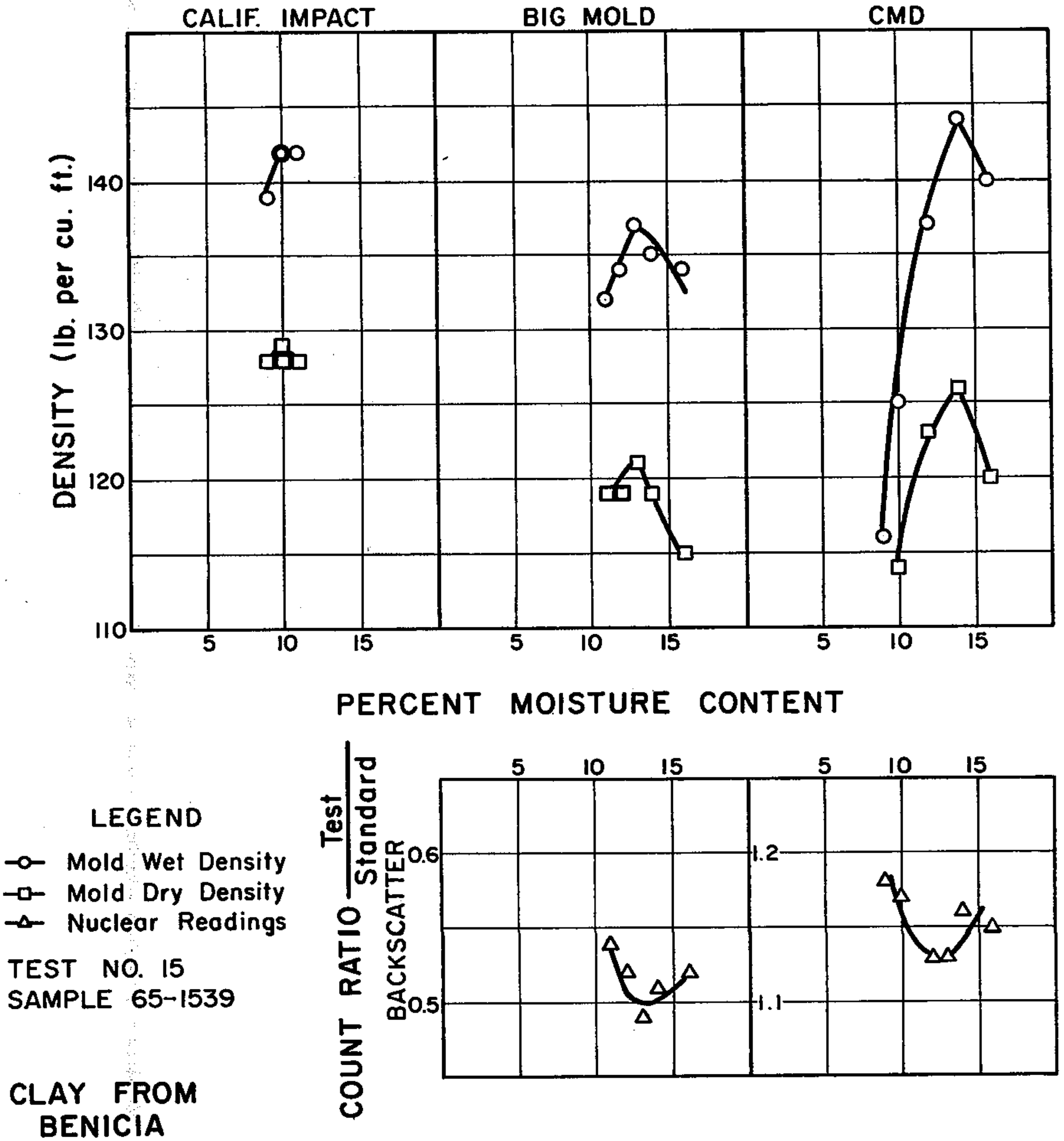
COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



INSTRUMENT: NUCLEAR – CHICAGO

Figure 20

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



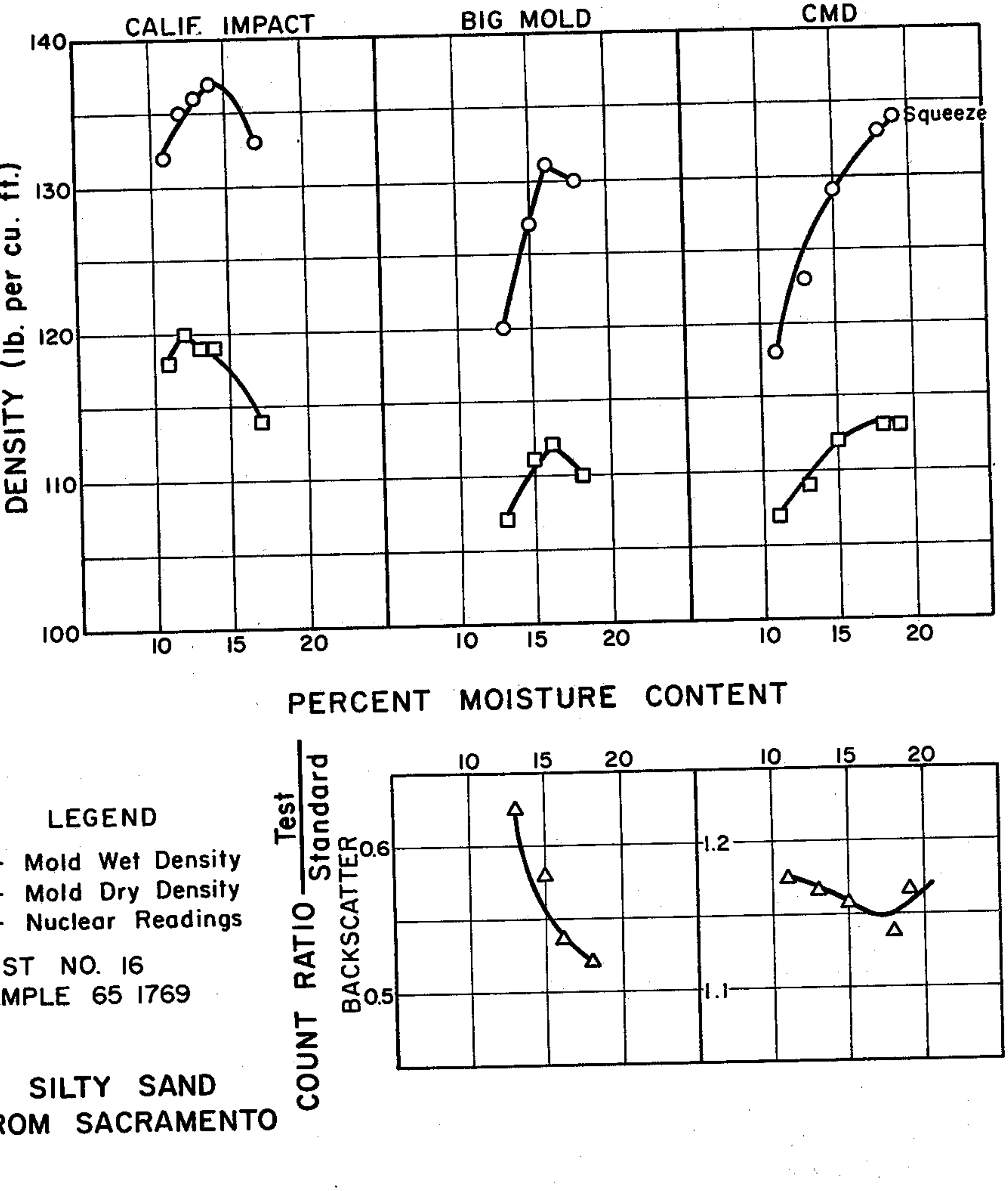
TEST NO. 15
SAMPLE 65-1539

CLAY FROM BENICIA

INSTRUMENT: NUCLEAR – CHICAGO

Figure 21

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

TEST NO. 16
SAMPLE 65 1769

SILTY SAND
FROM SACRAMENTO

INSTRUMENT: NUCLEAR – CHICAGO

Figure 22

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

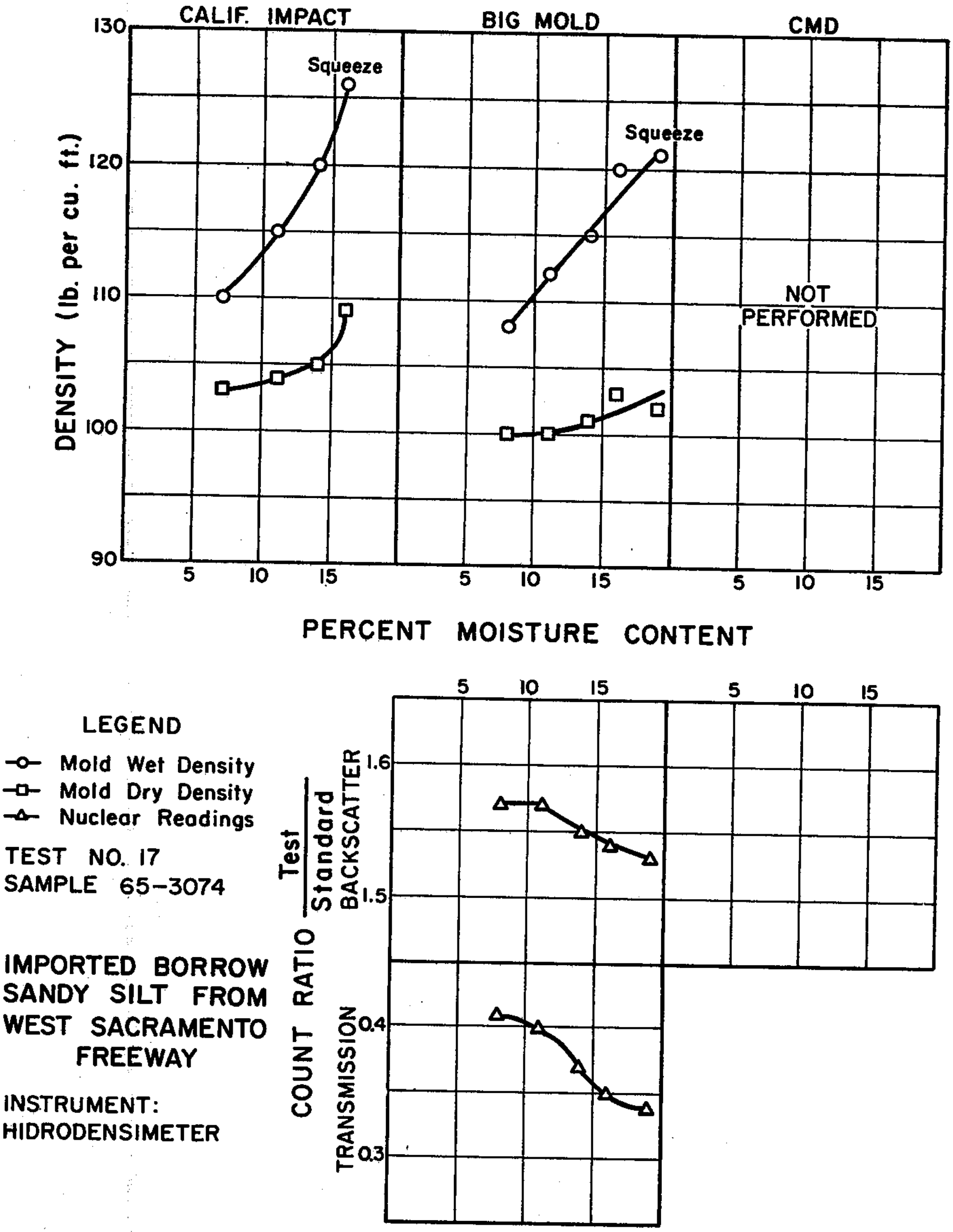


Figure 23

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

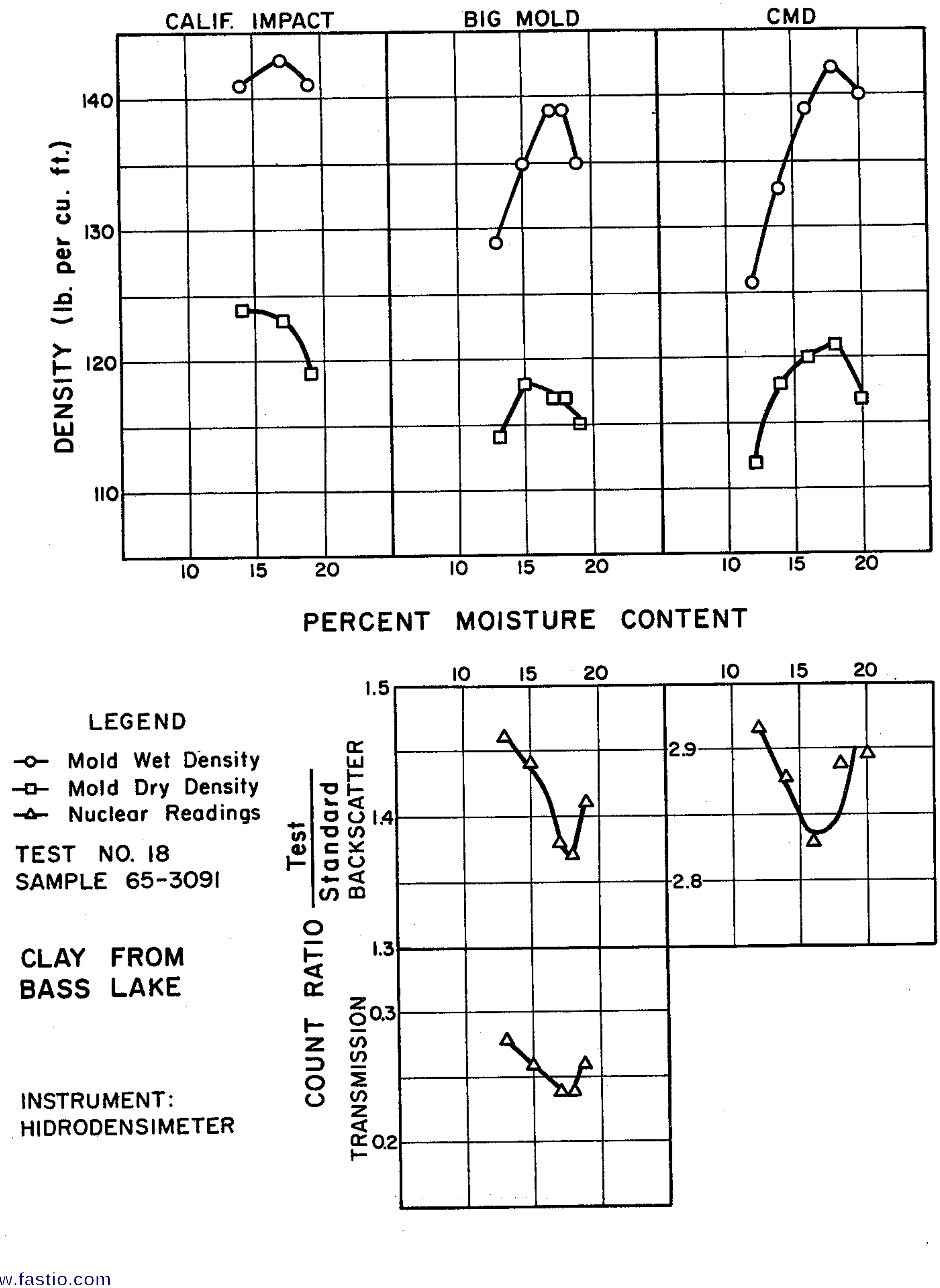


Figure 24

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

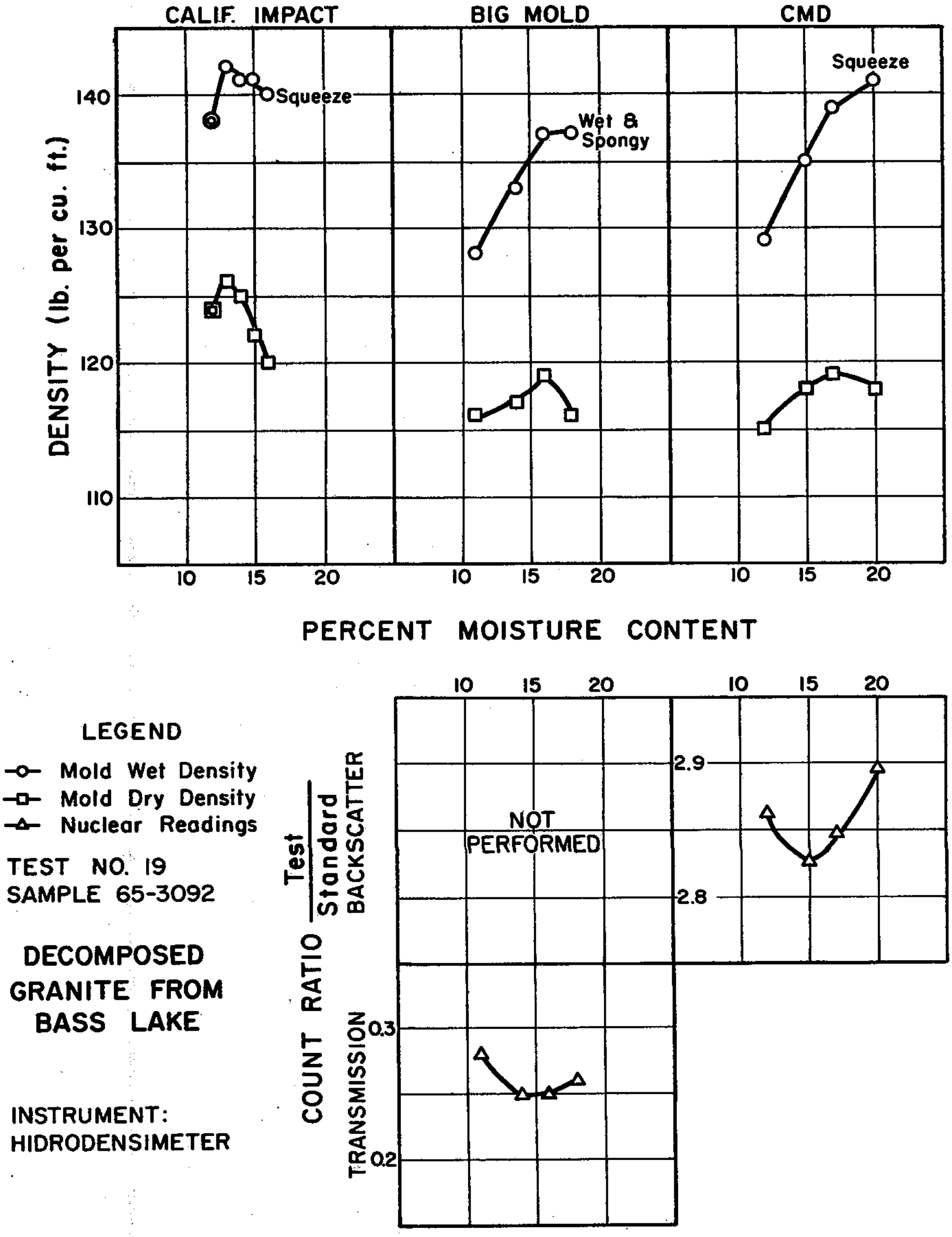


Figure 25

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

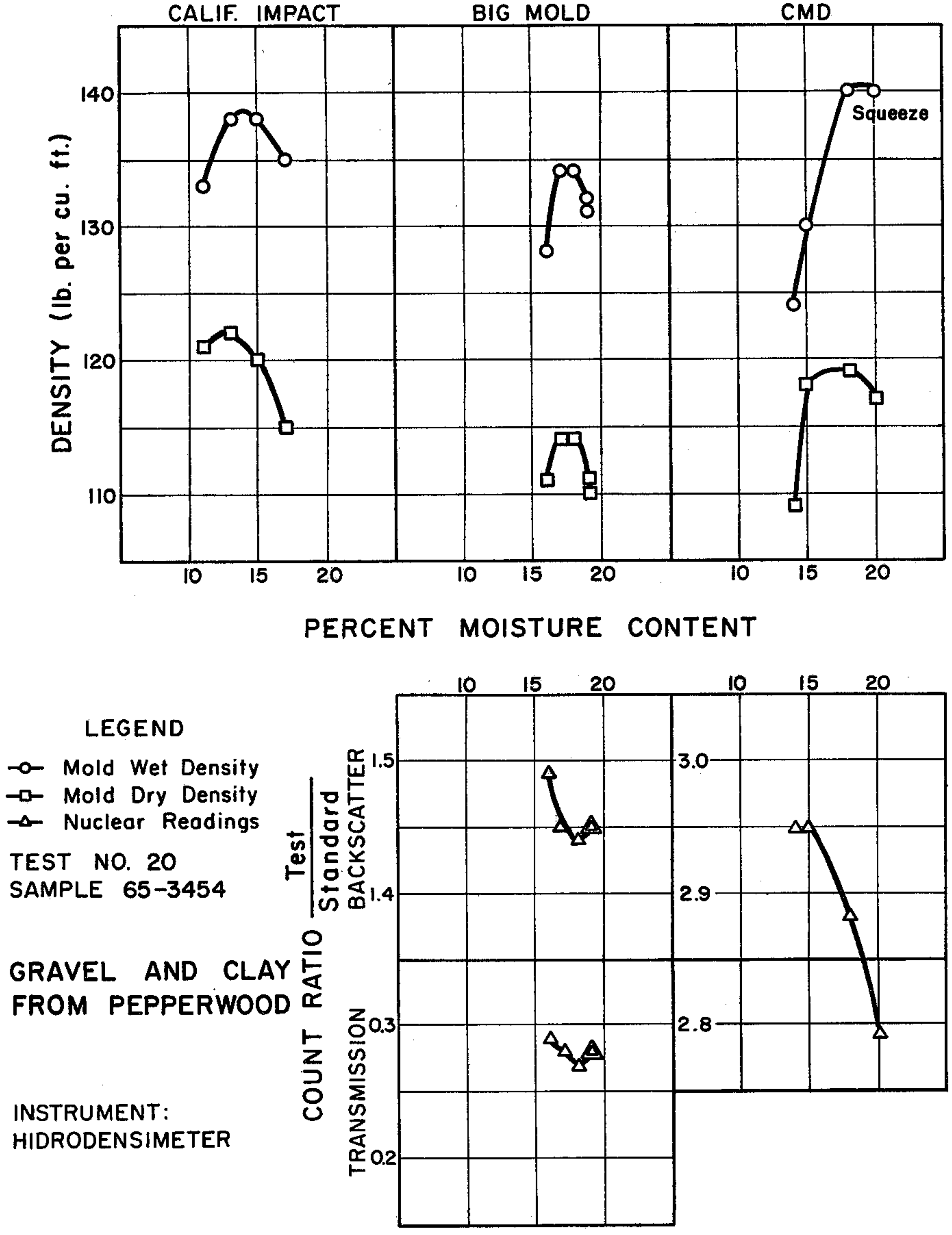
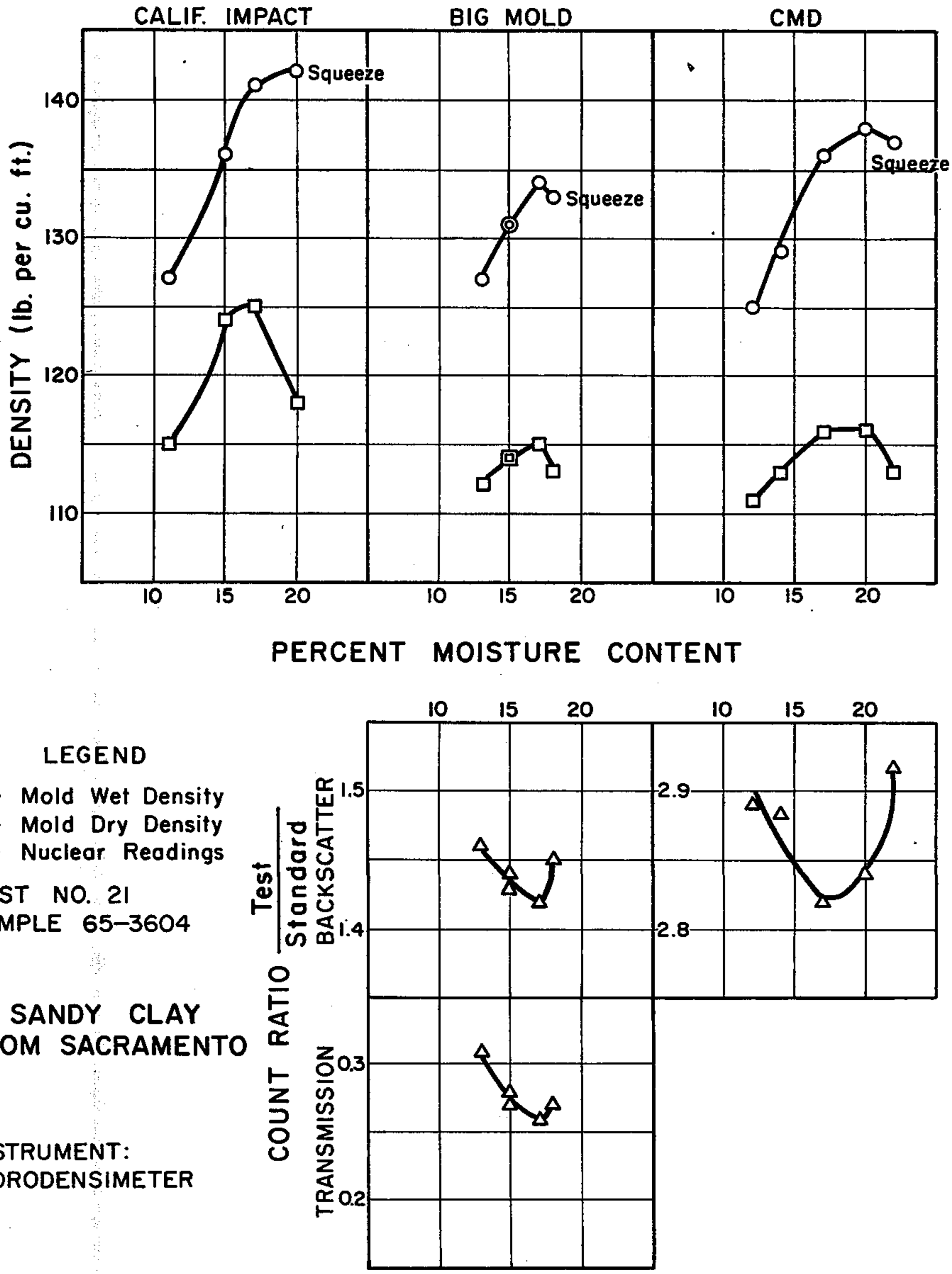


Figure 26

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

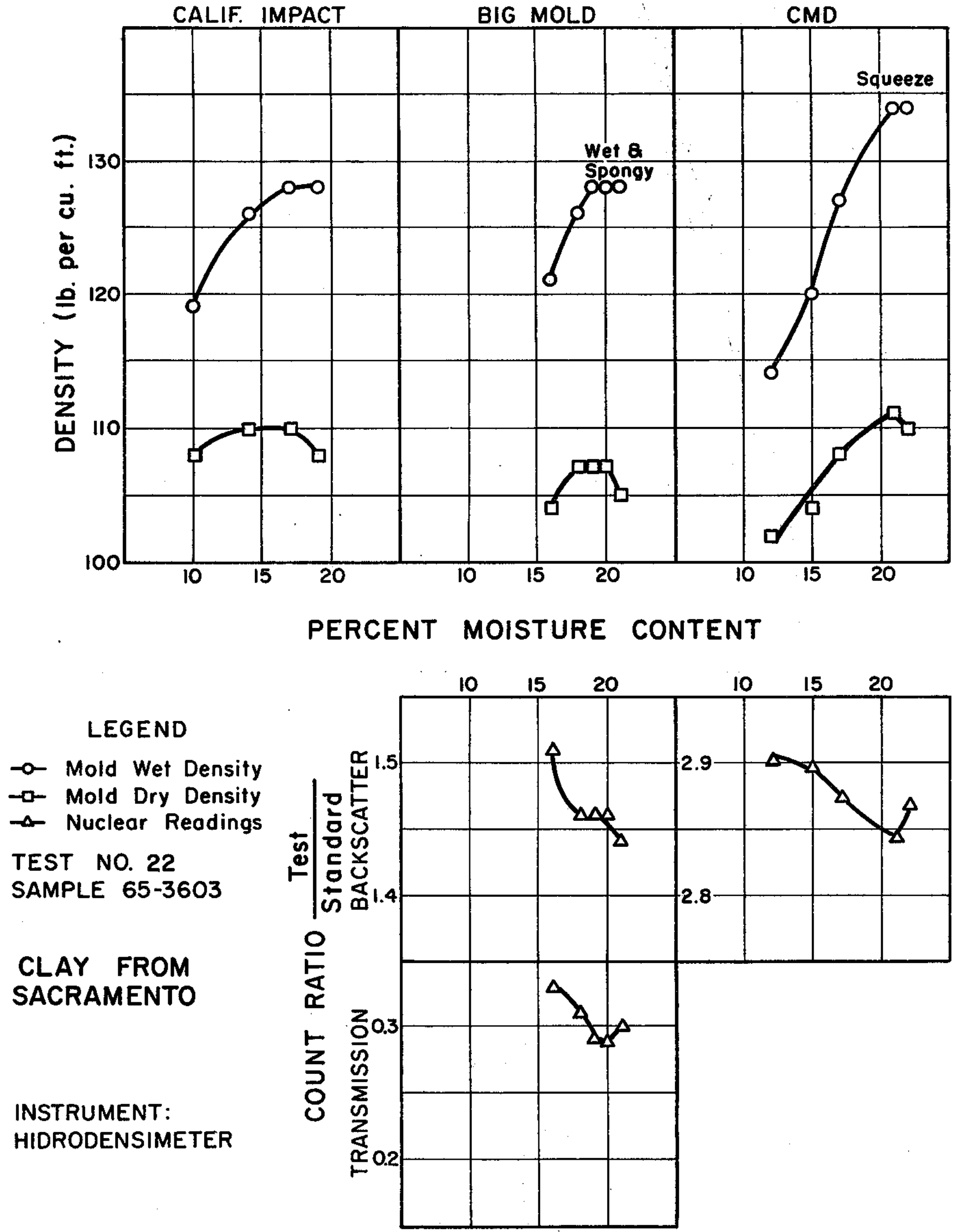
TEST NO. 21
SAMPLE 65–3604

SANDY CLAY
FROM SACRAMENTO

INSTRUMENT:
HIDRODENSIMETER

Figure 27

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



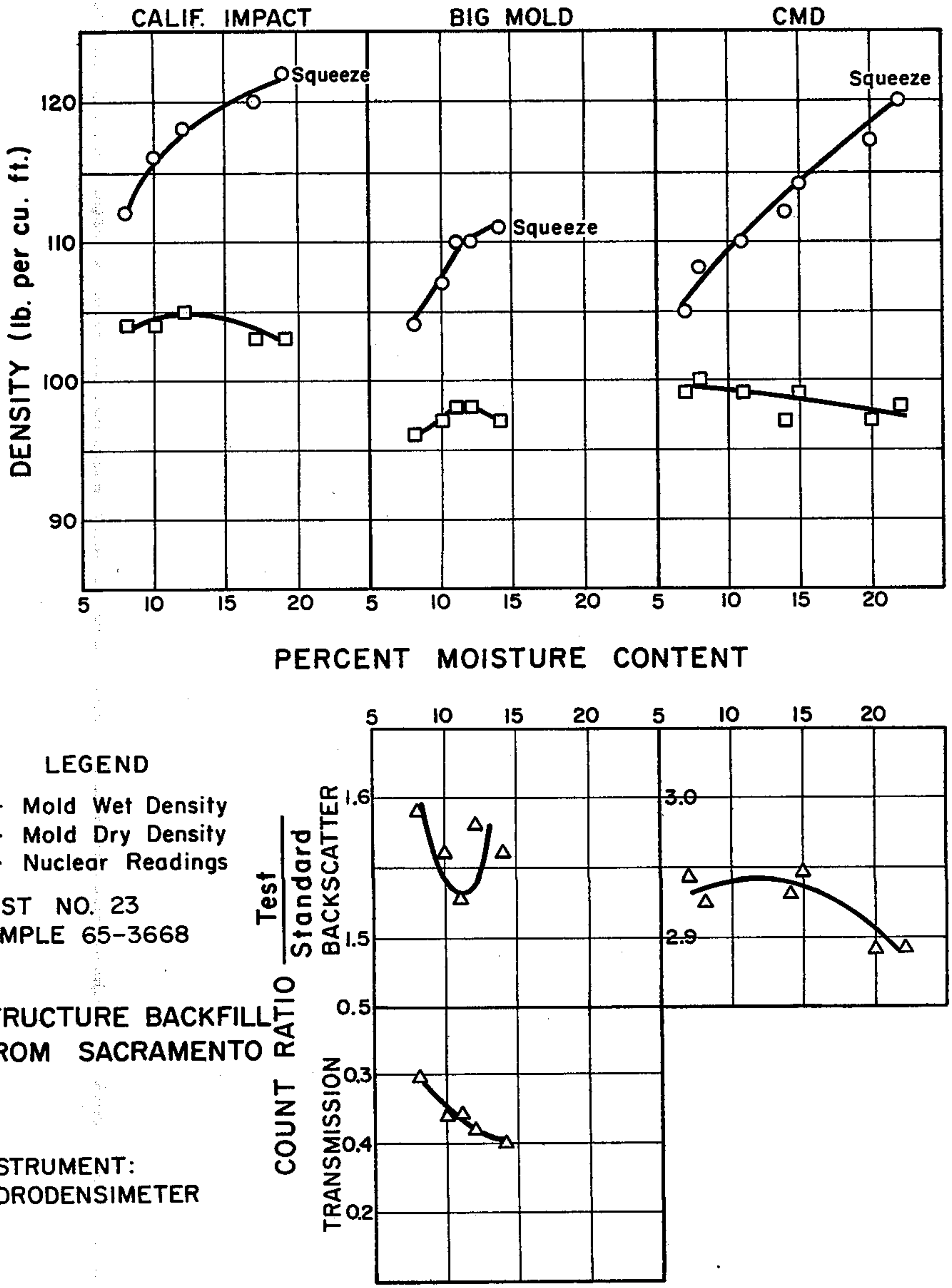
TEST NO. 22
SAMPLE 65-3603

CLAY FROM SACRAMENTO

INSTRUMENT:
HIDRODENSIMETER

Figure 28

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

TEST NO. 23
SAMPLE 65-3668

STRUCTURE BACKFILL FROM SACRAMENTO

INSTRUMENT:
HIDRODENSIMETER

Figure 29

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

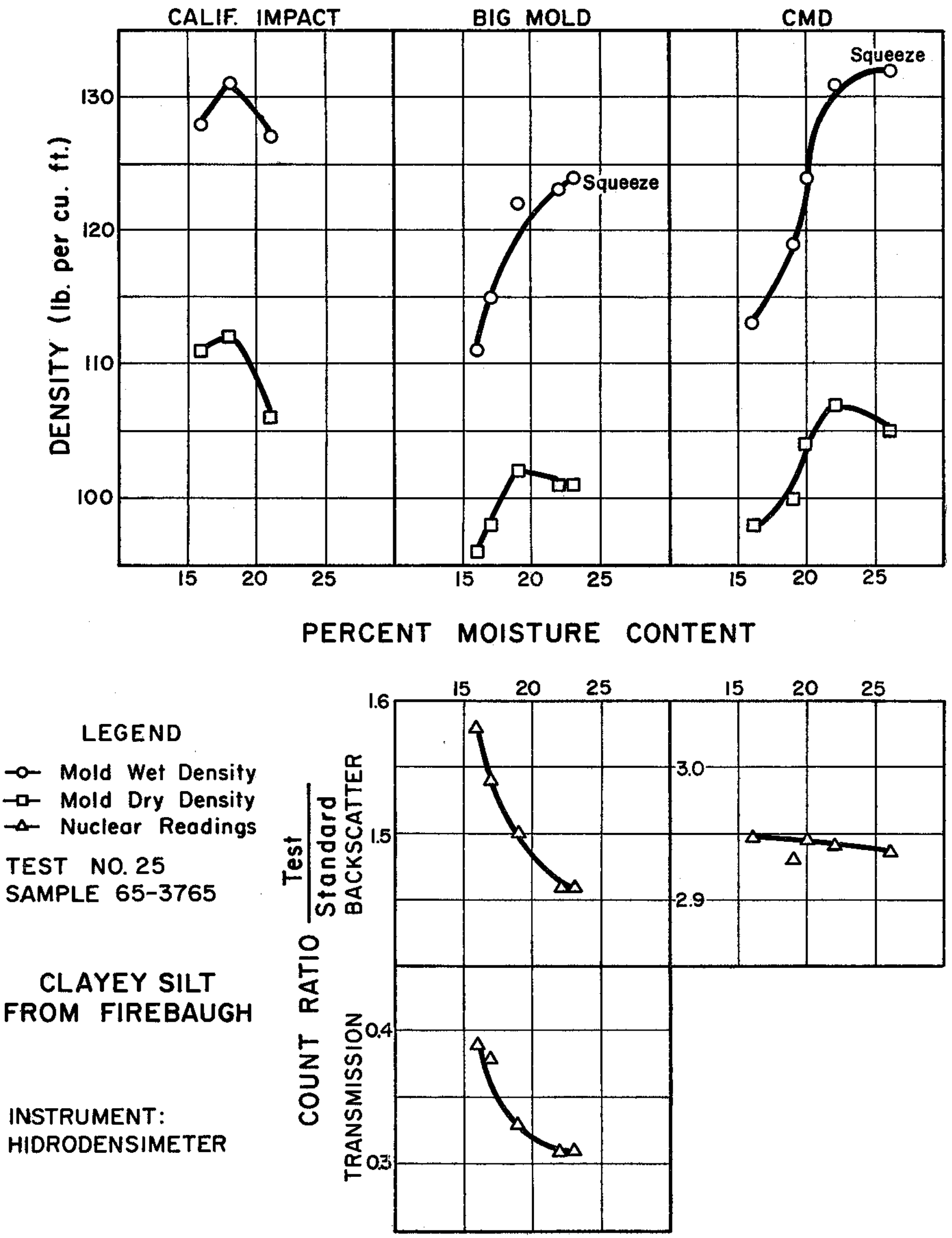


Figure 30

COMPARISON OF MOISTURE-DENSITY CURVES AND NUCLEAR READINGS

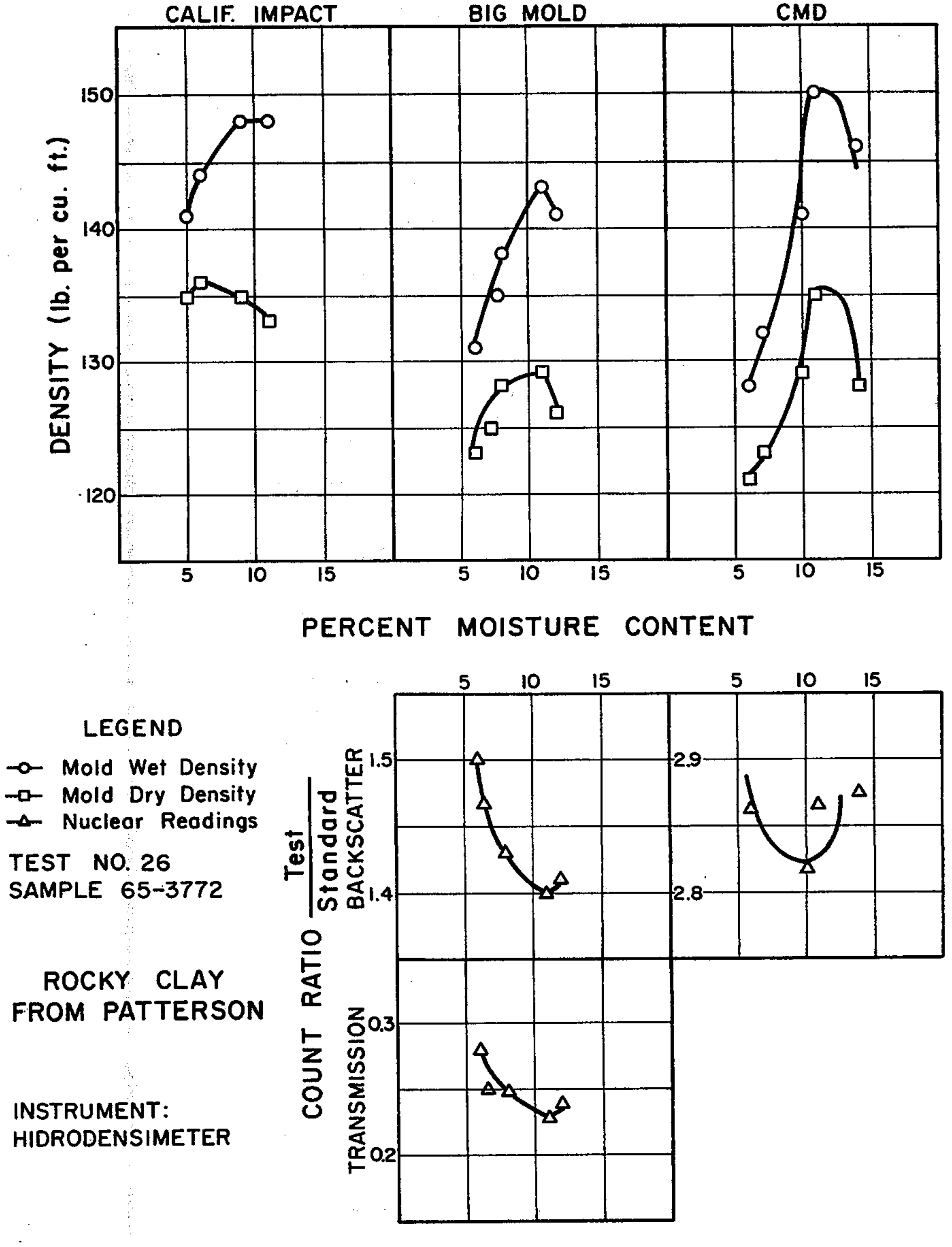
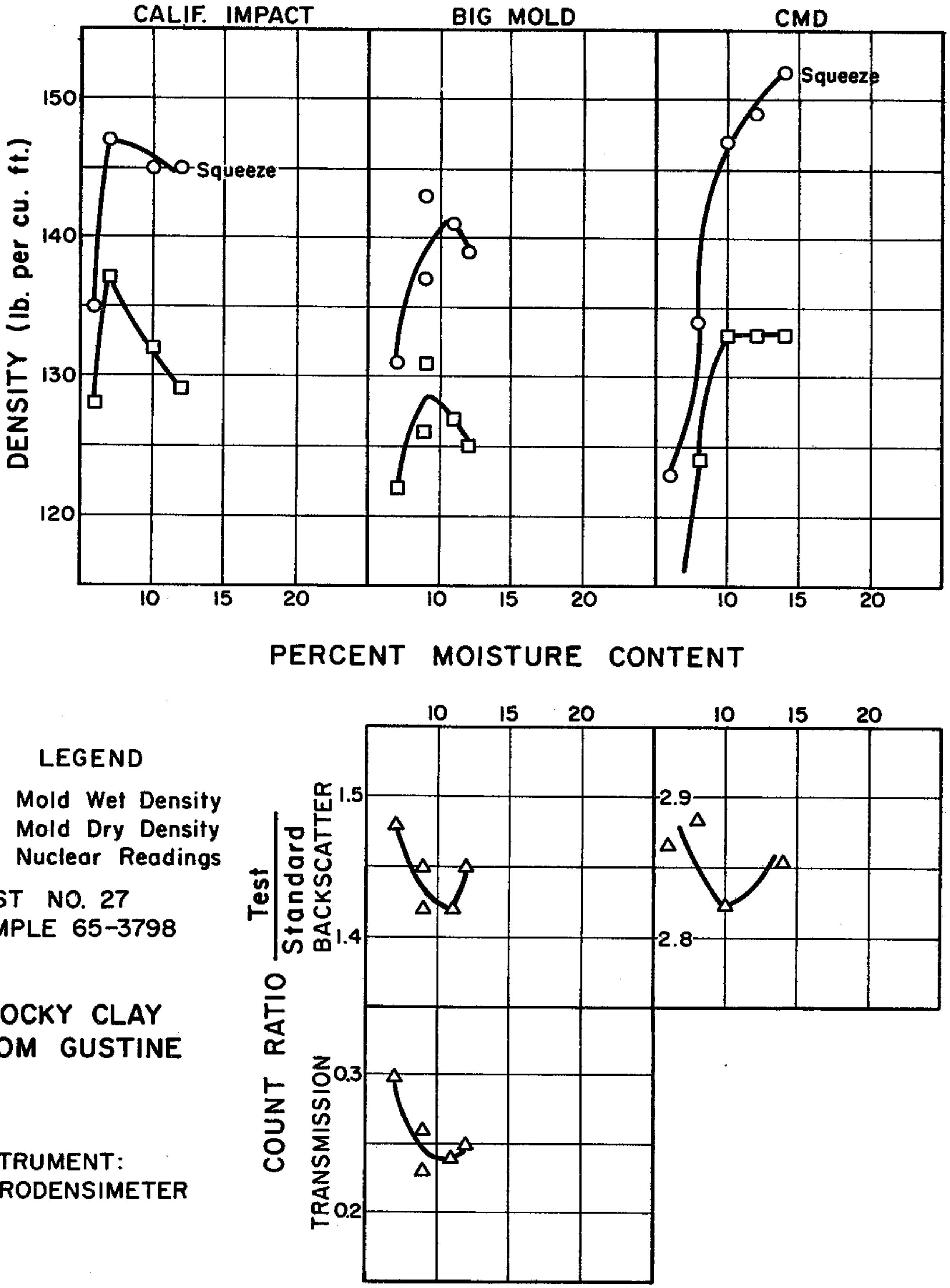


Figure 31

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

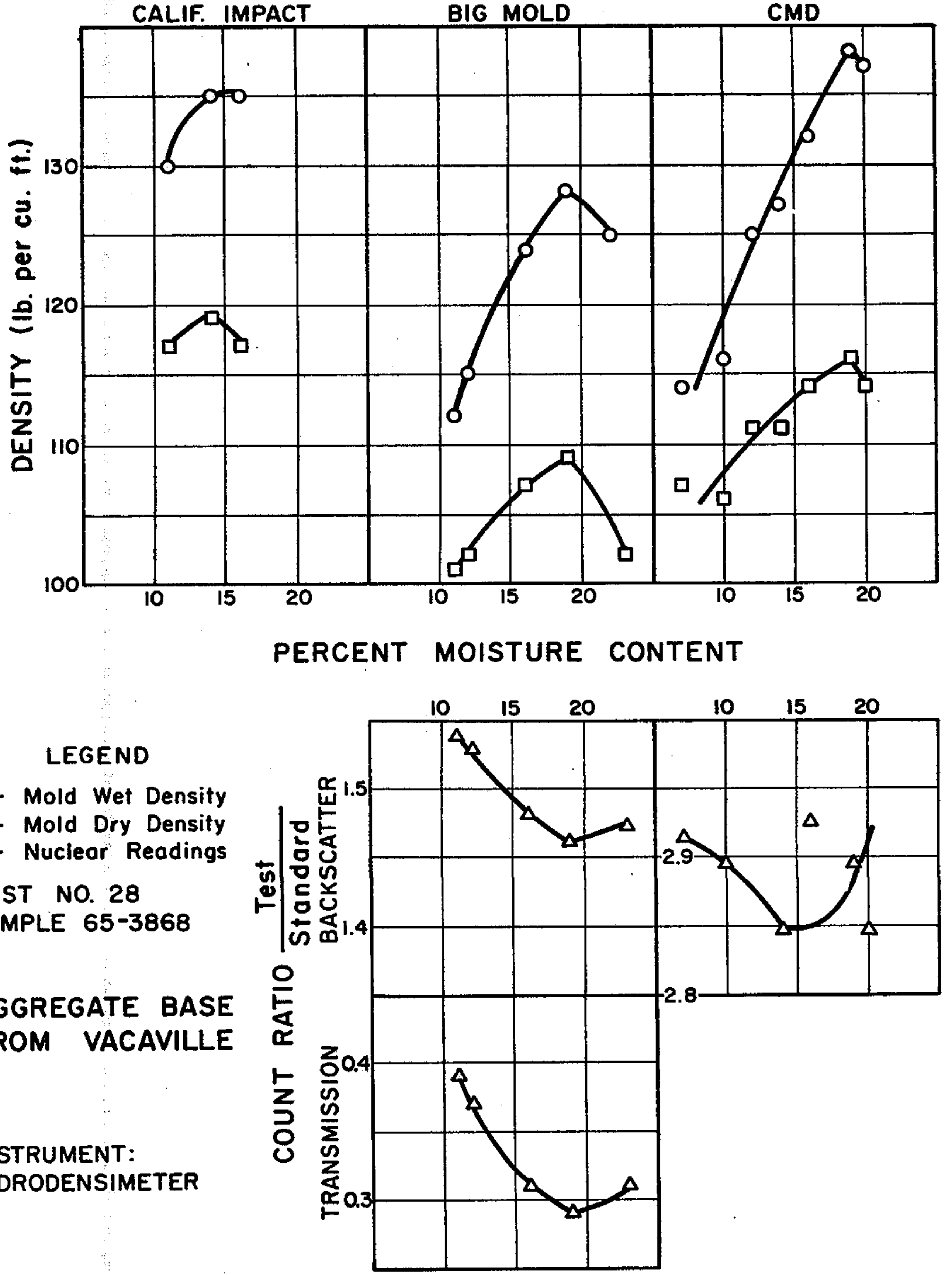
TEST NO. 27
SAMPLE 65-3798

ROCKY CLAY
FROM GUSTINE

INSTRUMENT:
HIDRODENSIMETER

Figure 32

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

TEST NO. 28
SAMPLE 65-3868

AGGREGATE BASE FROM VACAVILLE

INSTRUMENT:
HIDRODENSIMETER

Figure 33

COMPARISON OF MOISTURE-DENSITY CURVES AND NUCLEAR READINGS

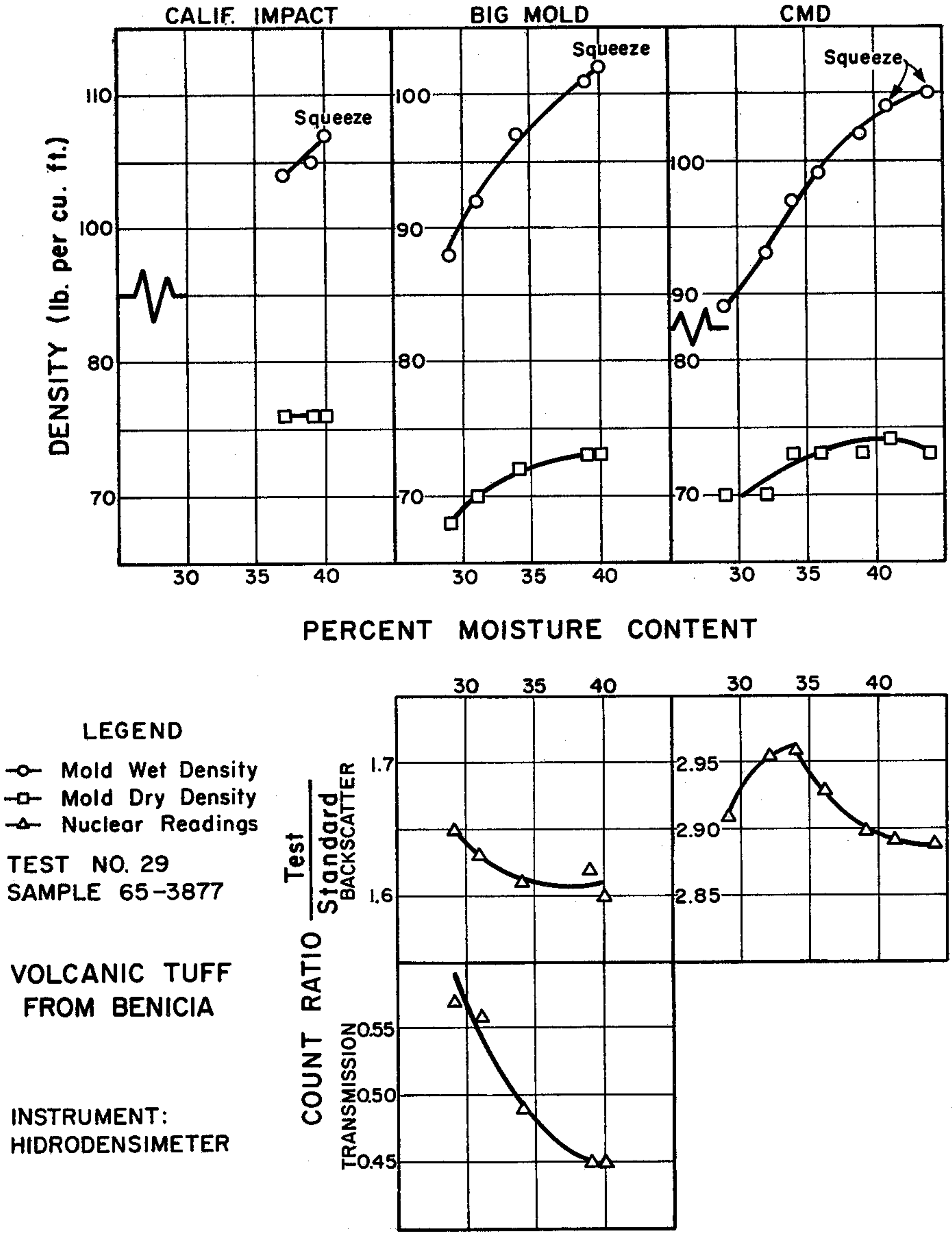
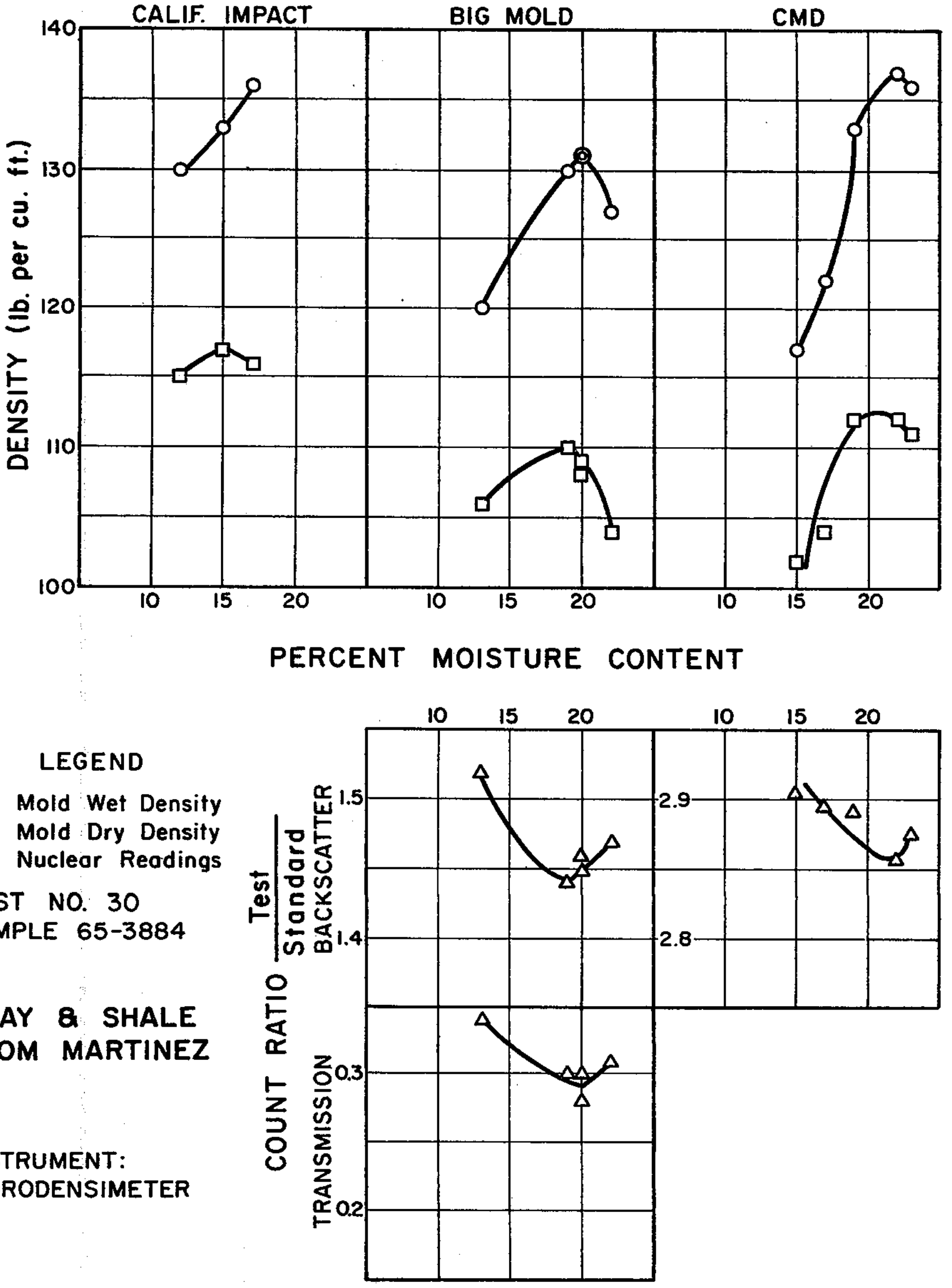


Figure 34

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS



LEGEND

- Mold Wet Density
- Mold Dry Density
- Nuclear Readings

TEST NO. 30
SAMPLE 65-3884

CLAY & SHALE FROM MARTINEZ

INSTRUMENT:
HIDRODENSIMETER

Figure 35

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

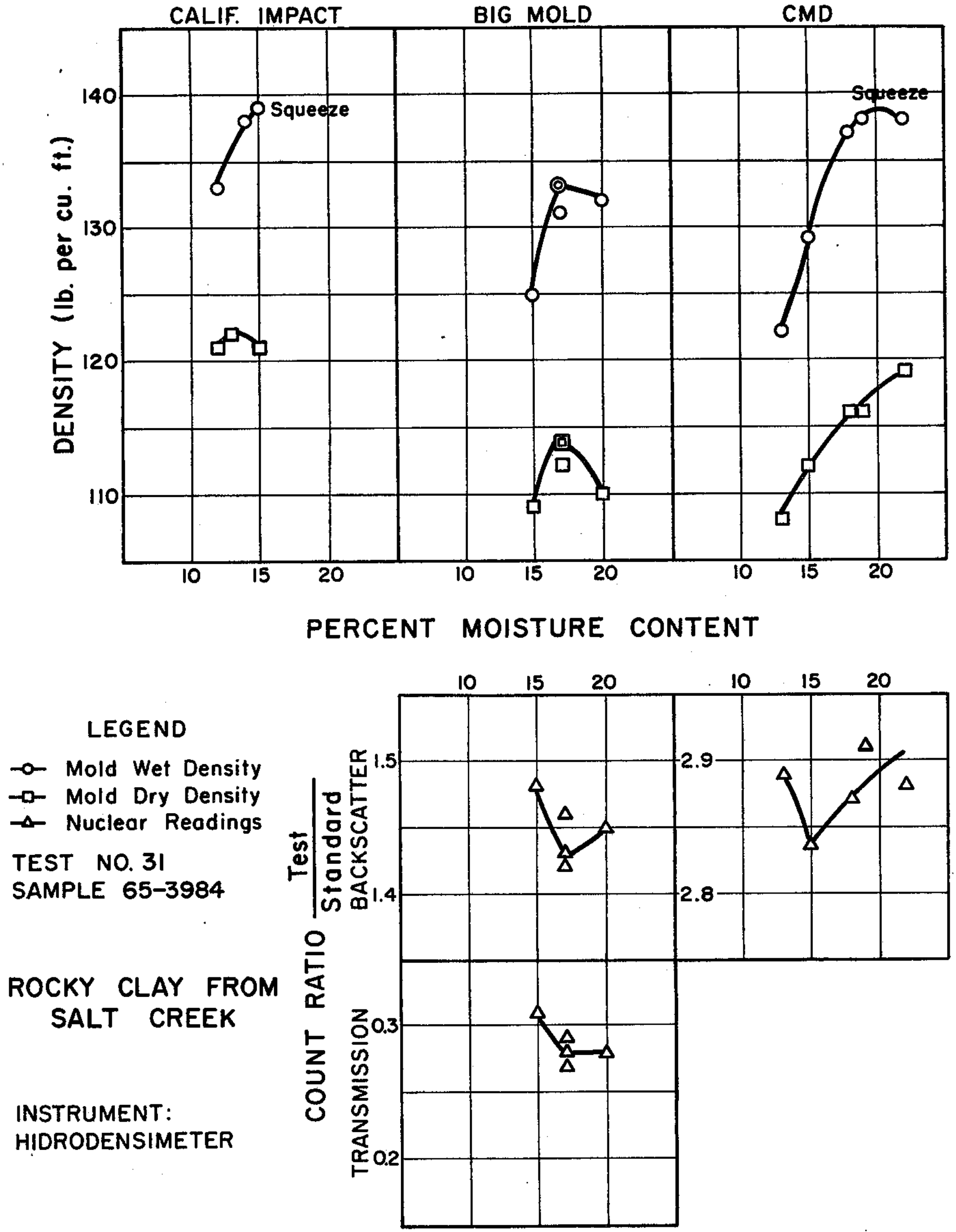


Figure 36

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

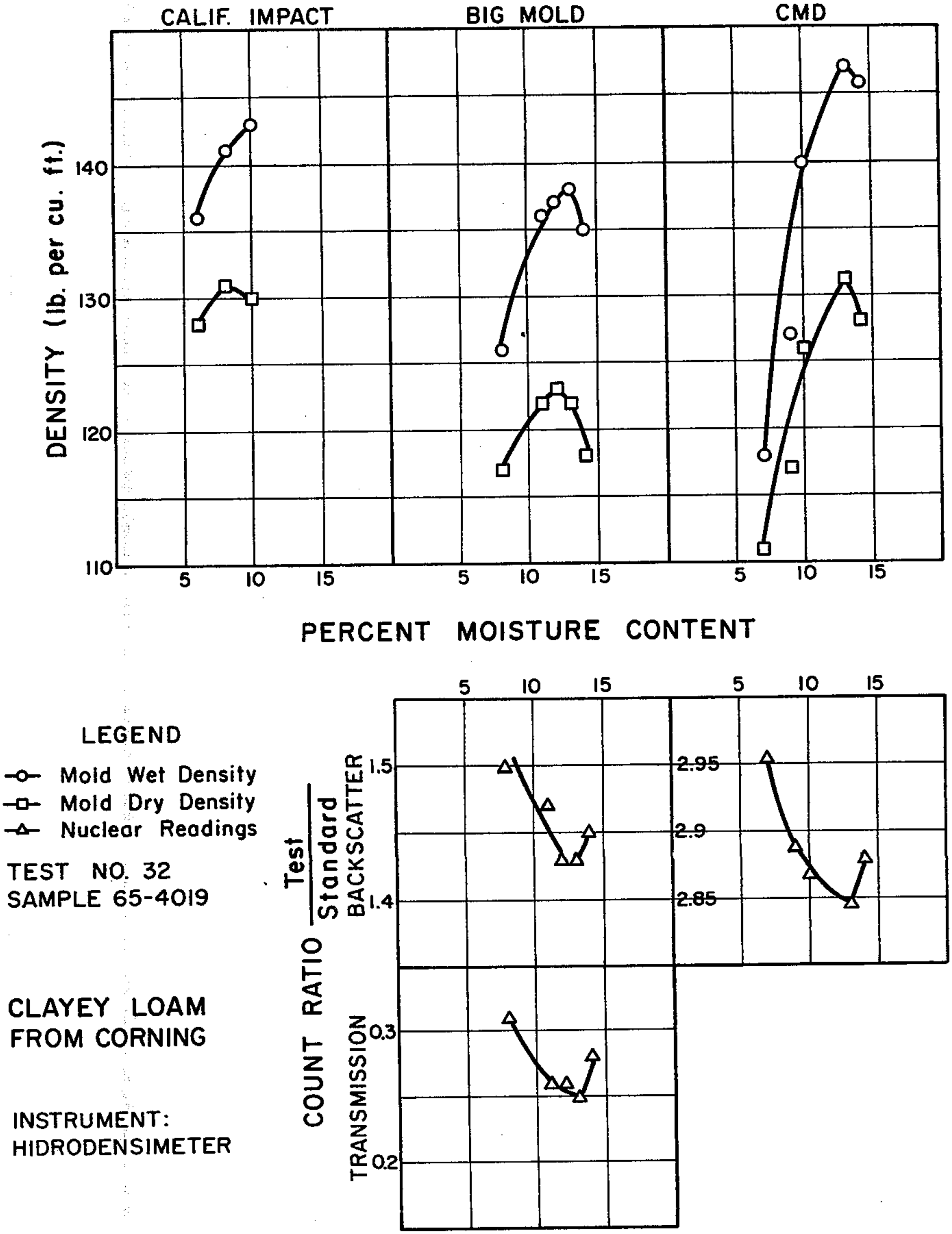


Figure 37

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

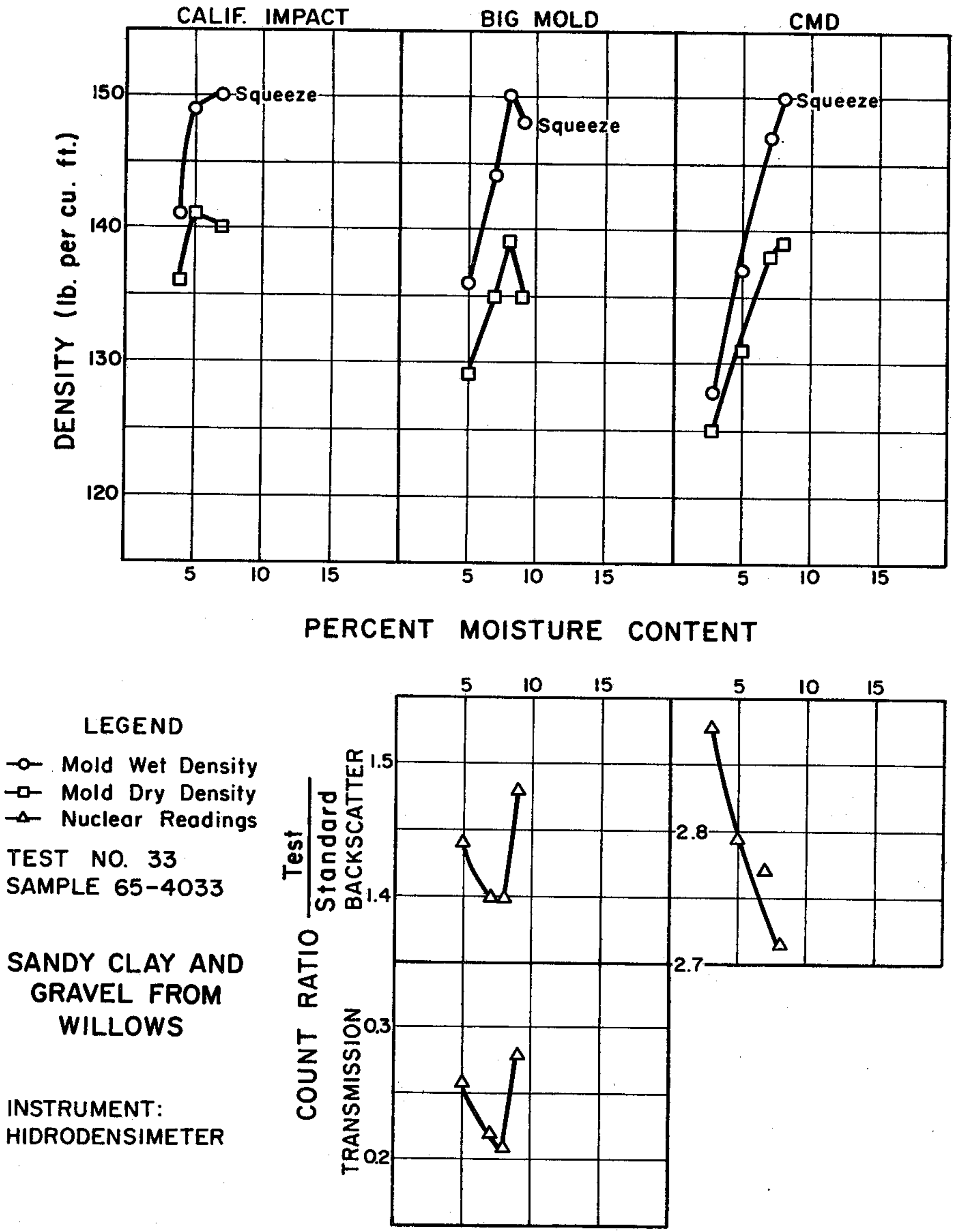


Figure 38

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

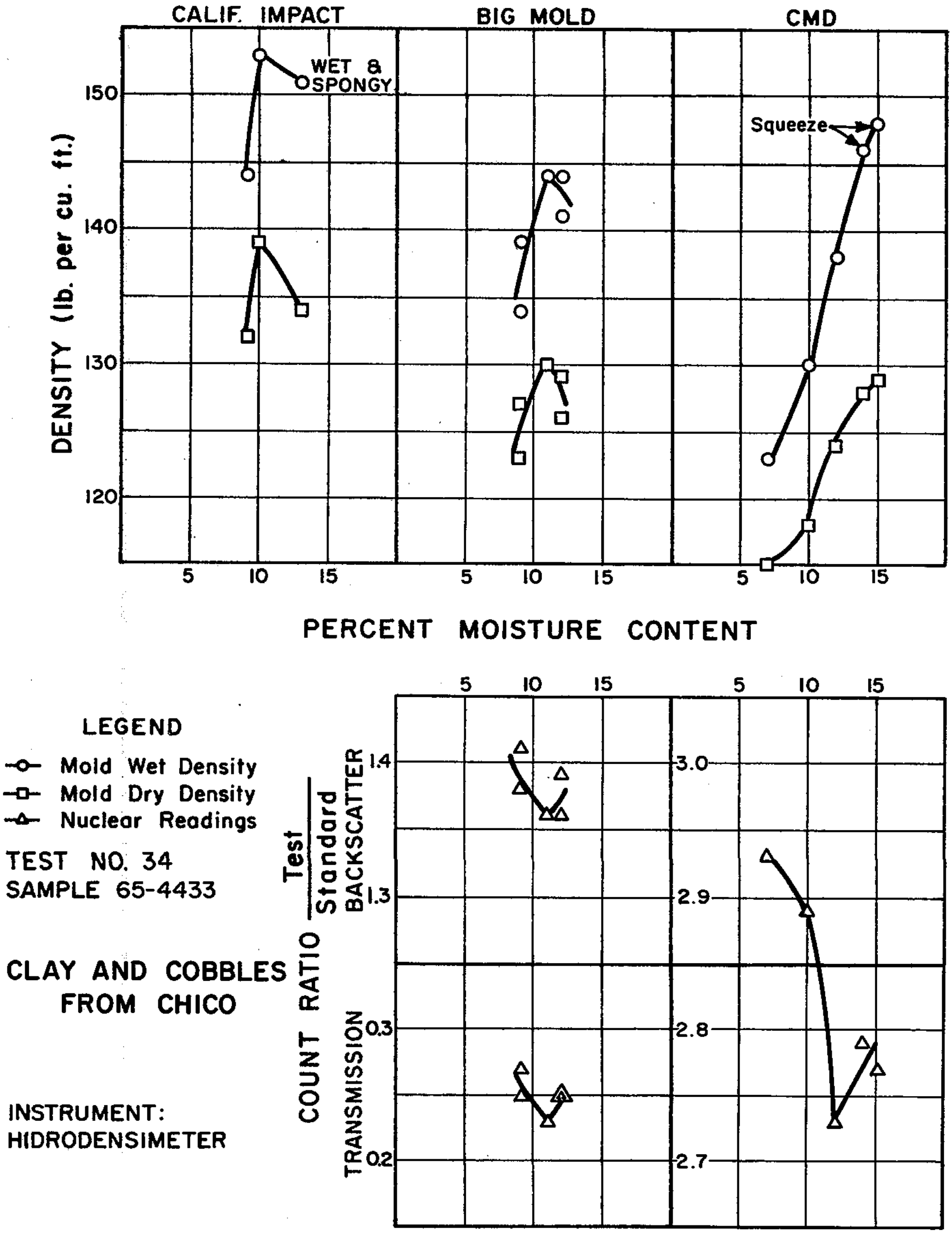


Figure 39

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

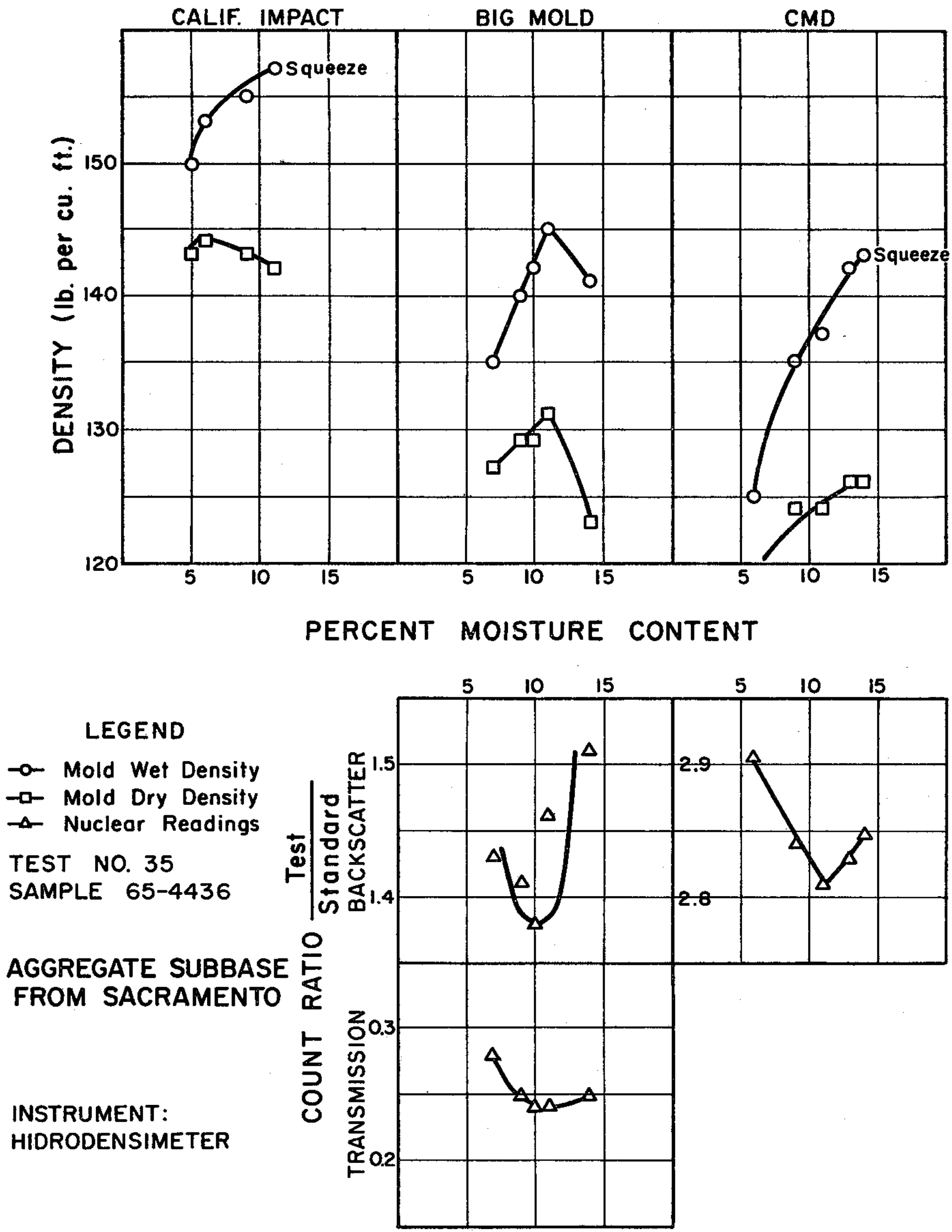


Figure 40

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

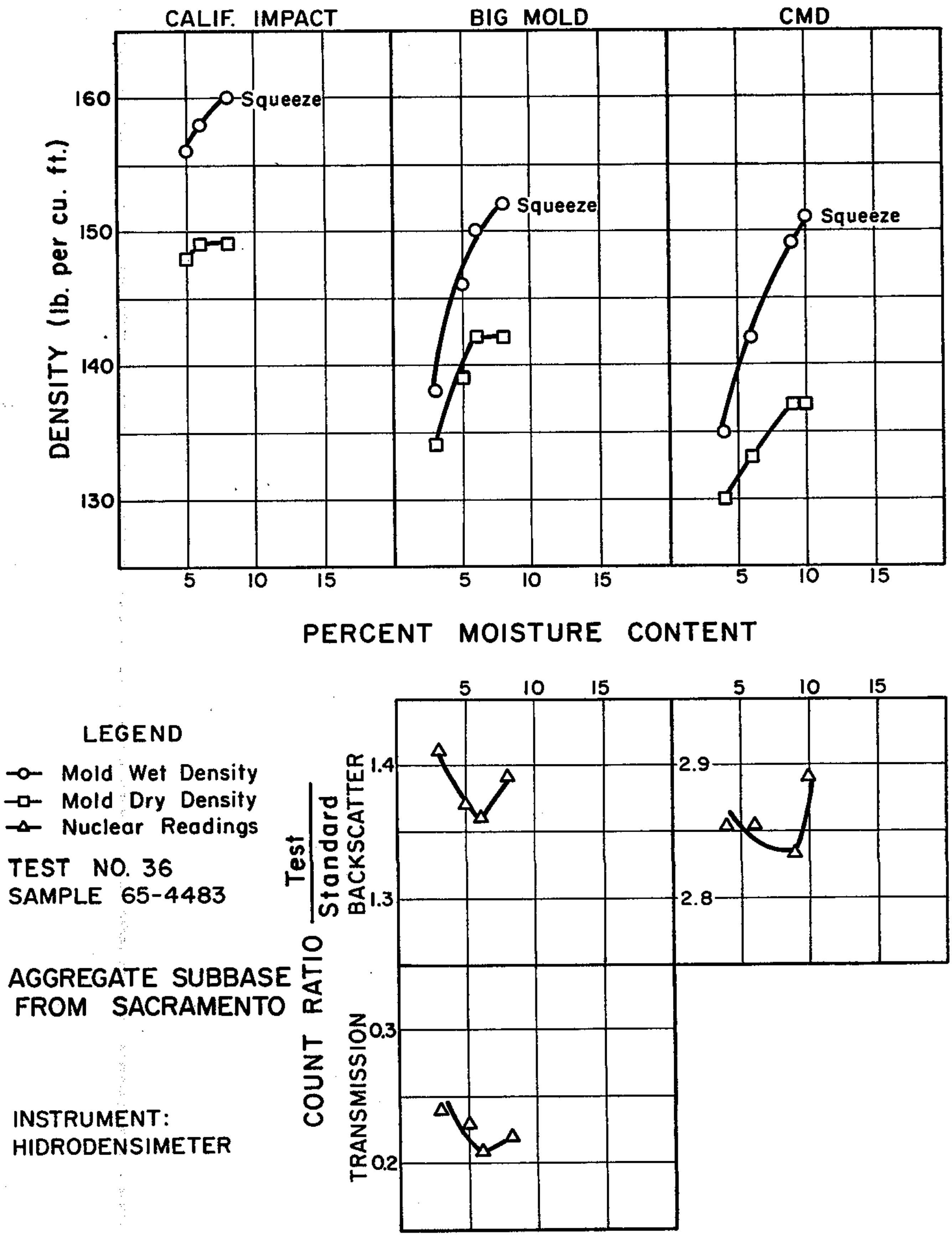


Figure 41

COMPARISON OF MOISTURE DENSITY CURVES AND NUCLEAR READINGS

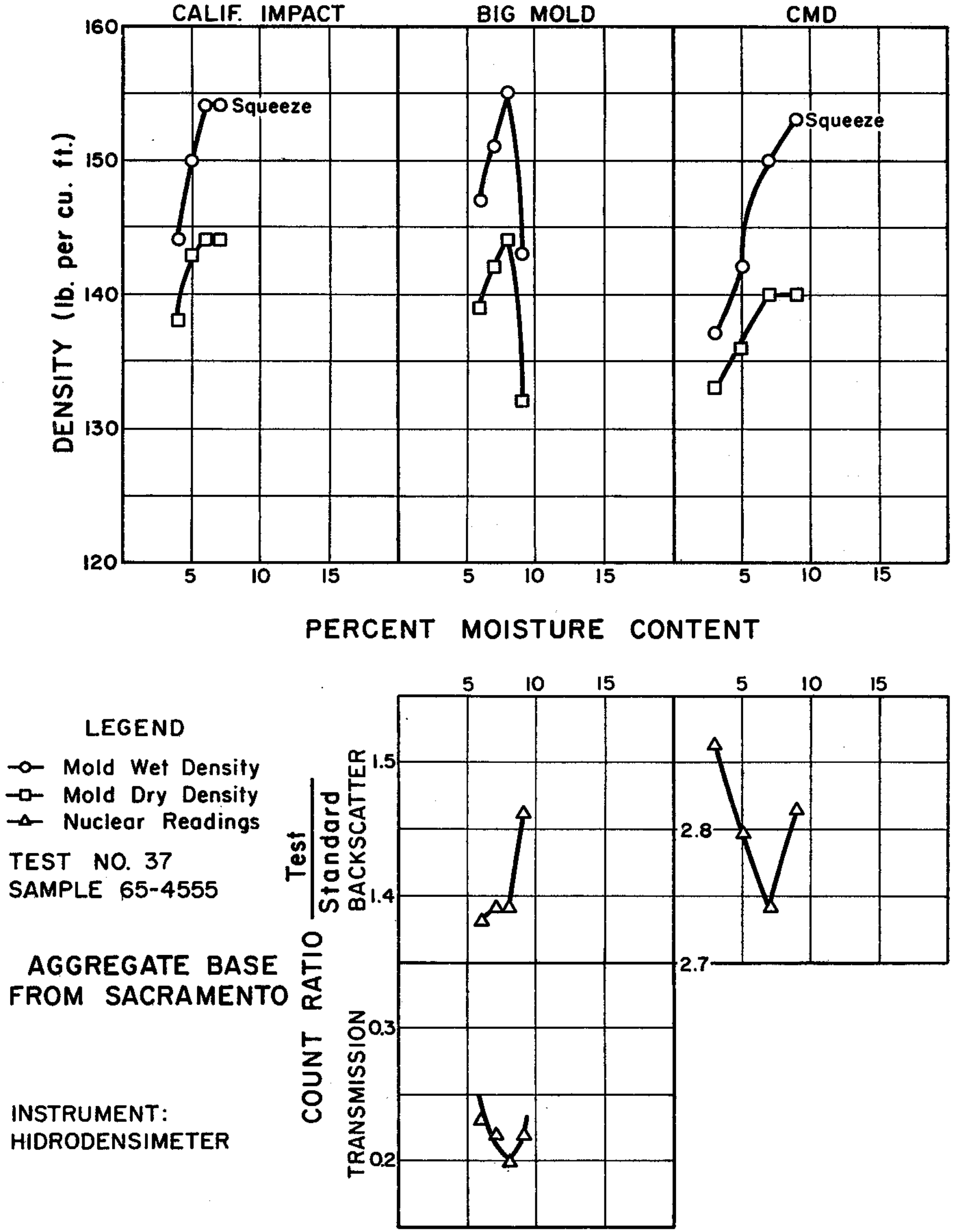


Figure 42

APPARENT RELATIONSHIP OF BIG MOLD MAXIMUM DENSITIES TO COMPACTIVE EFFORT

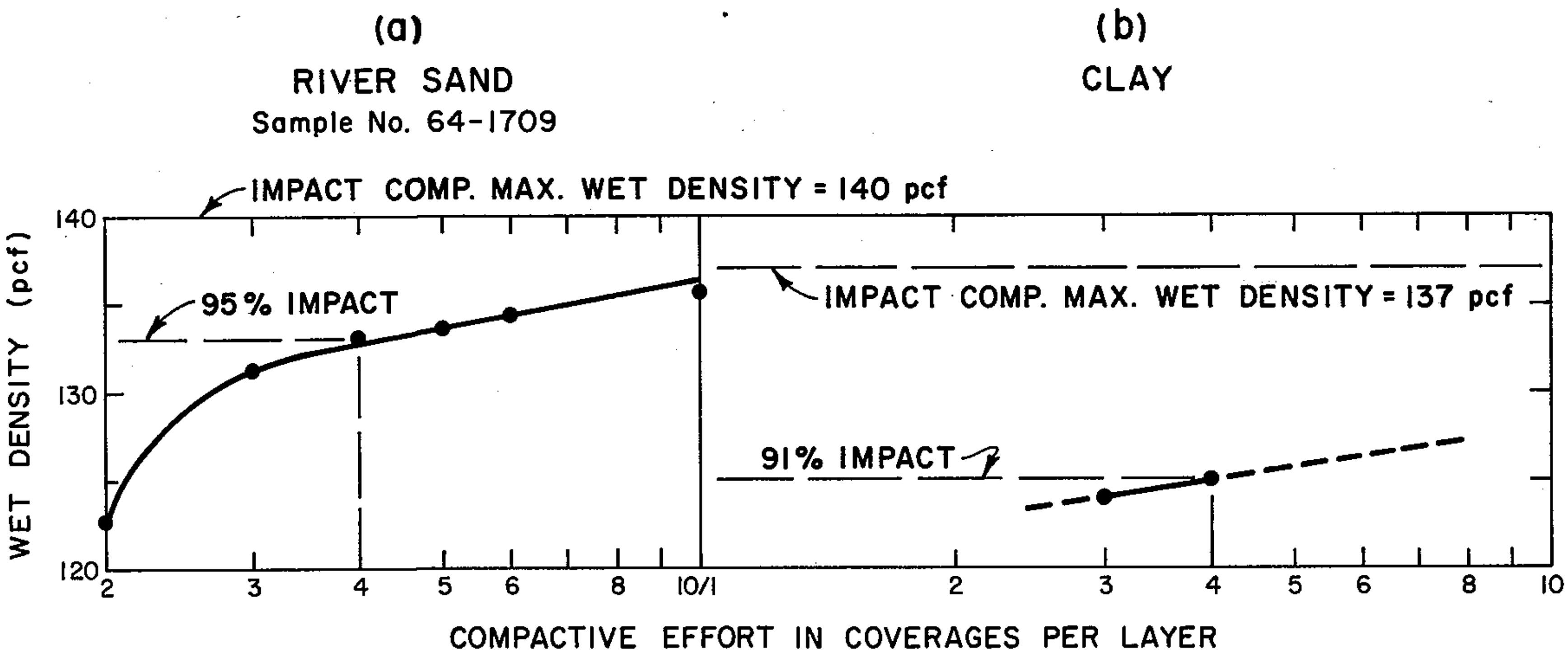
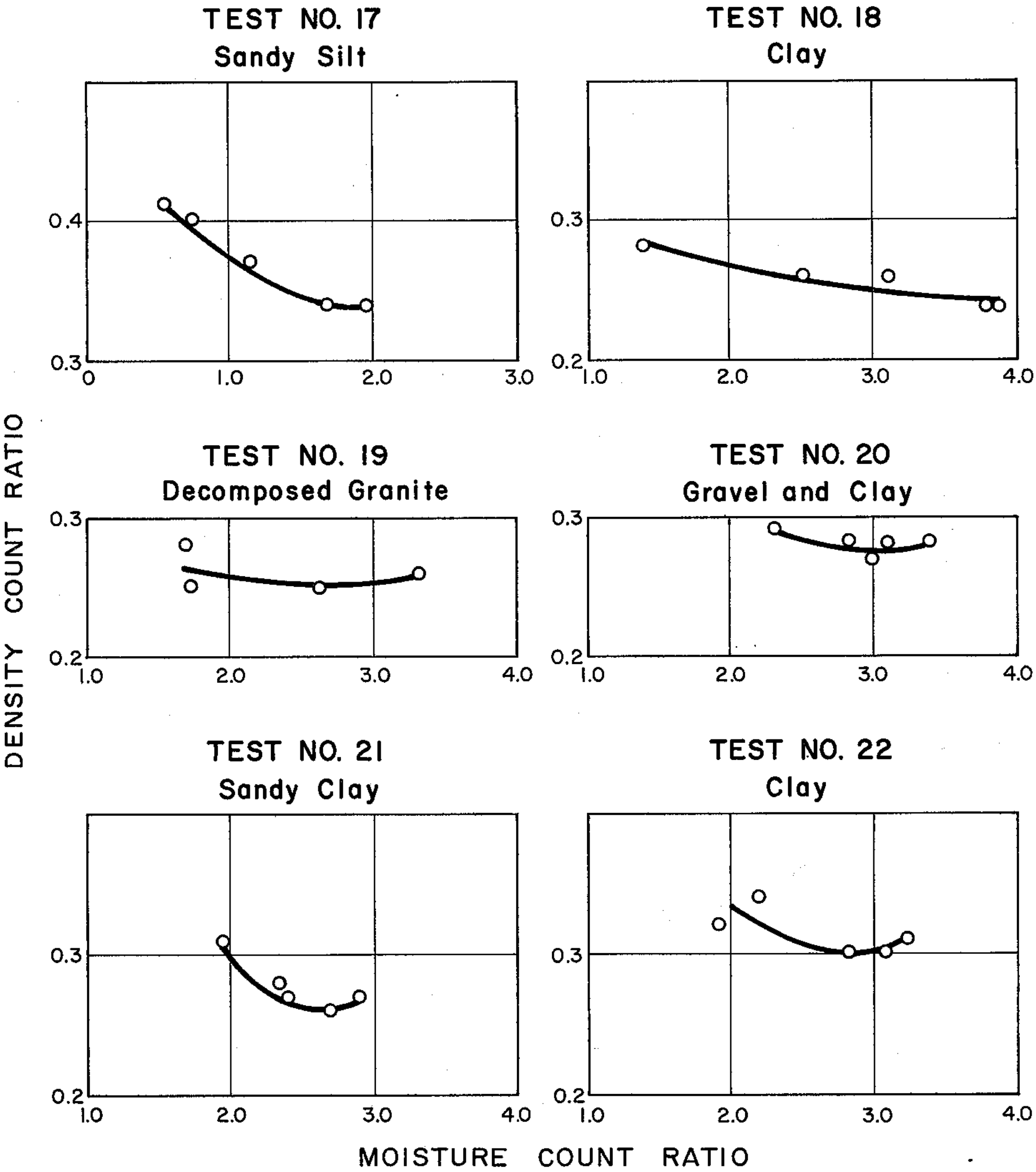


Figure 43

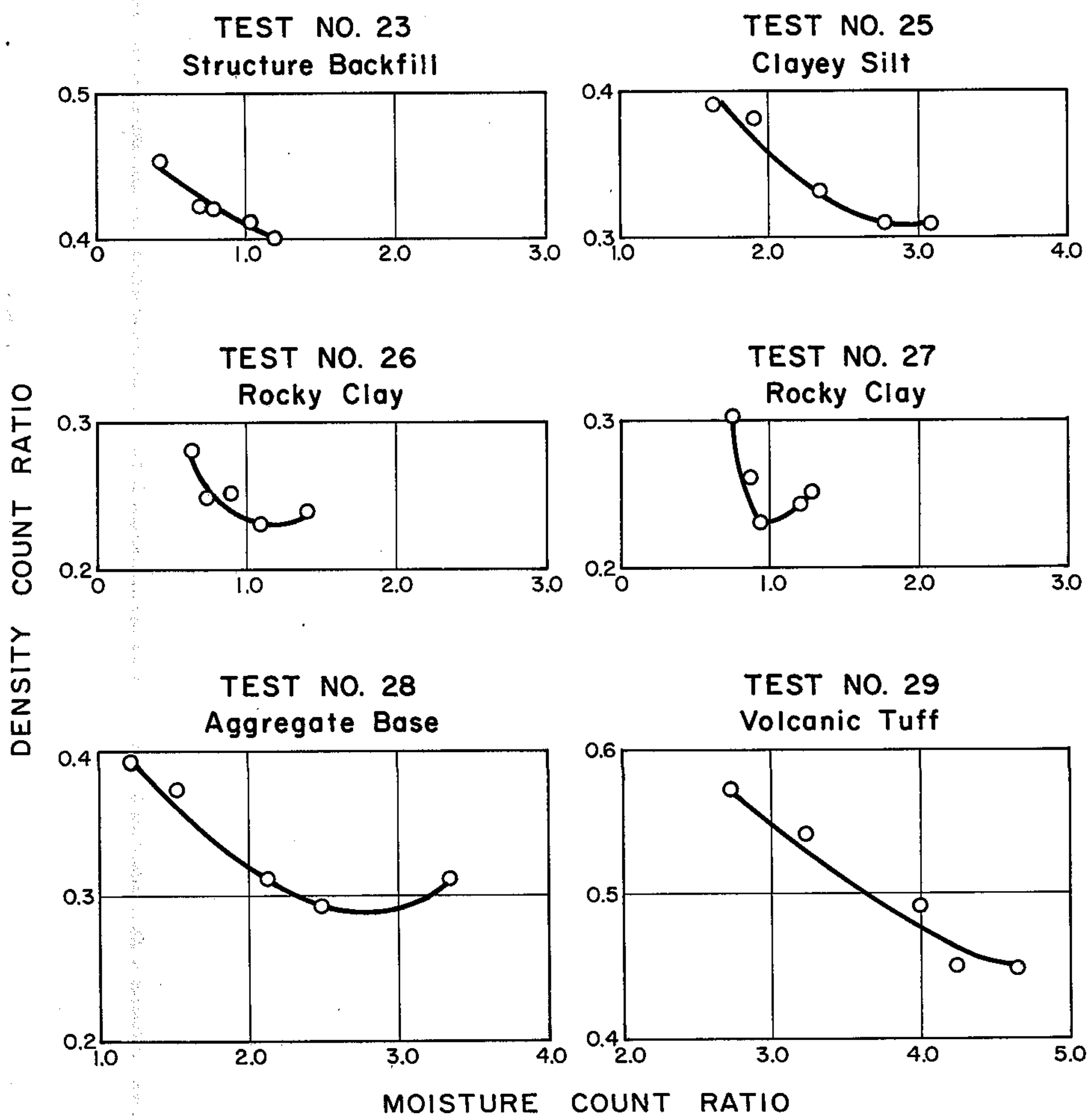
MOISTURE AND DENSITY COUNT RATIO RELATIONSHIP

6 INCH TRANSMISSION IN BIG MOLD



MOISTURE AND DENSITY COUNT RATIO RELATIONSHIP

6 INCH TRANSMISSION IN BIG MOLD



MOISTURE AND DENSITY COUNT RATIO RELATIONSHIP

6 INCH TRANSMISSION IN BIG MOLD

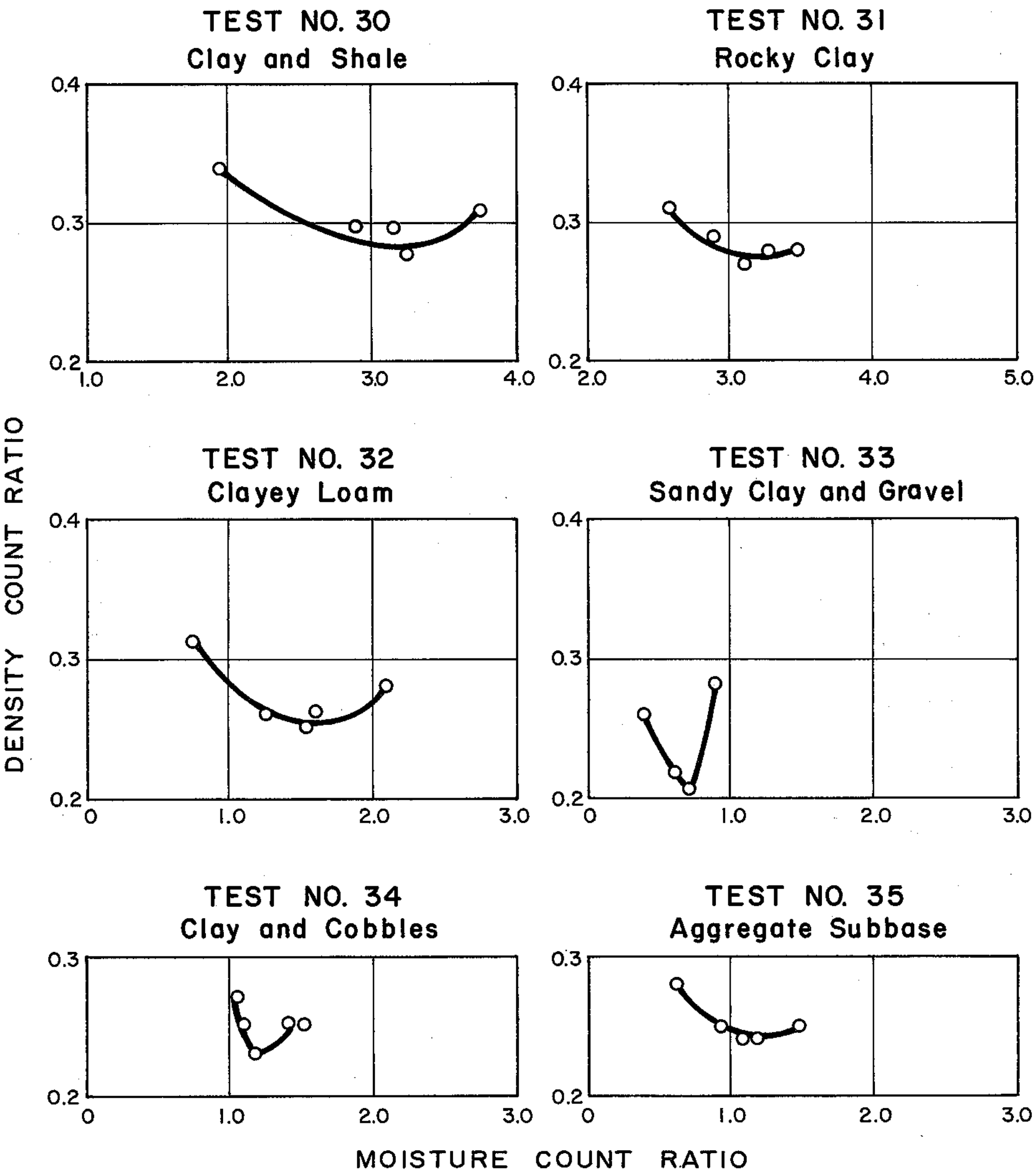
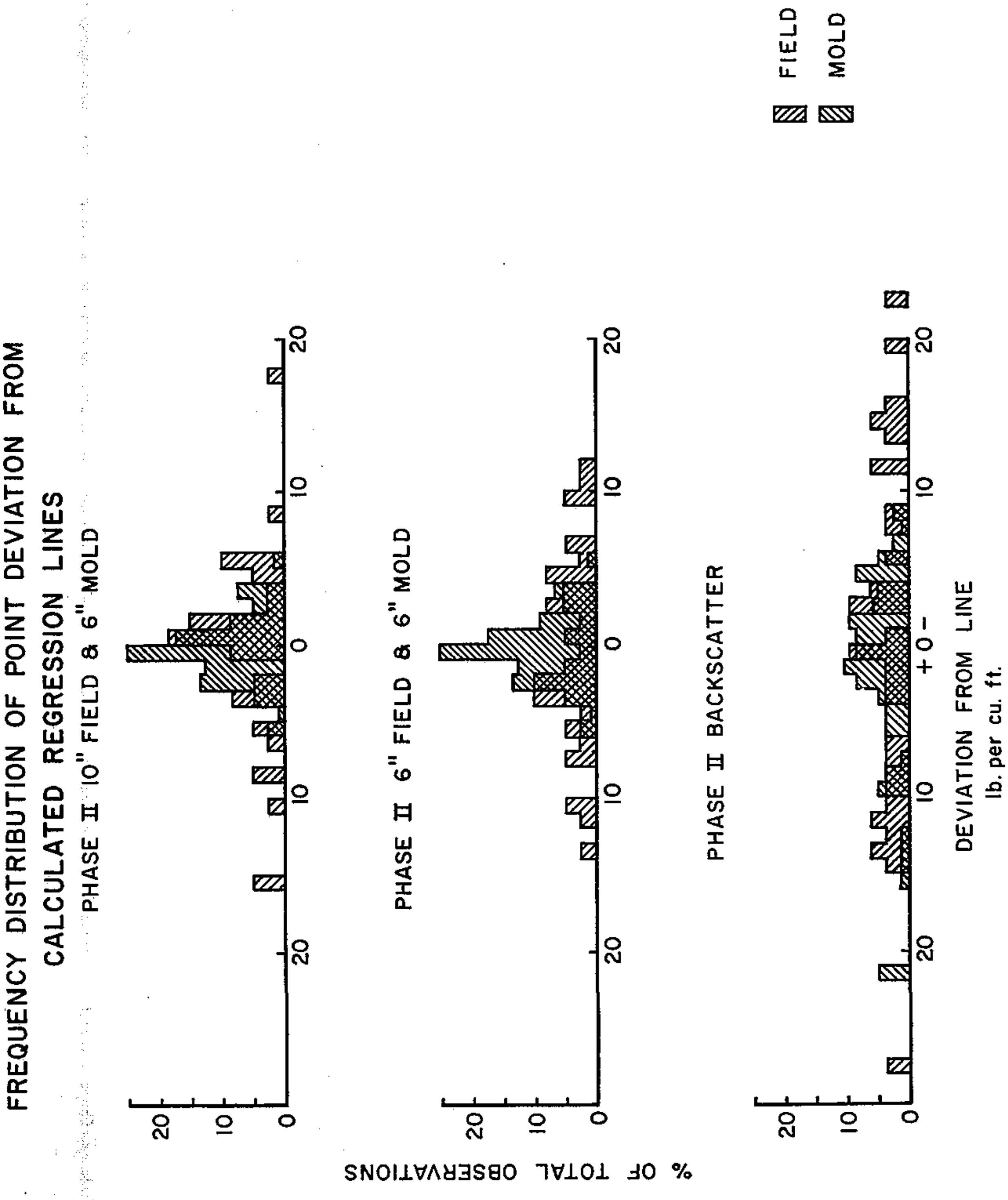


Figure 46


FREQUENCY DISTRIBUTION OF POINT DEVIATION FROM
CALCULATED REGRESSION LINES
PHASE II 10" FIELD & 6" MOLD
PHASE II 6" FIELD & 6" MOLD
PHASE II BACKSCATTER
FIELD
MOLD
% OF TOTAL OBSERVATIONS
DEVIATION FROM LINE
lb. per cu. ft.
+ 0 −
20
10
0
10
20

Nuclear Instruments Used in this Study

Photo 47. Field application of Nuclear-Chicago density gage

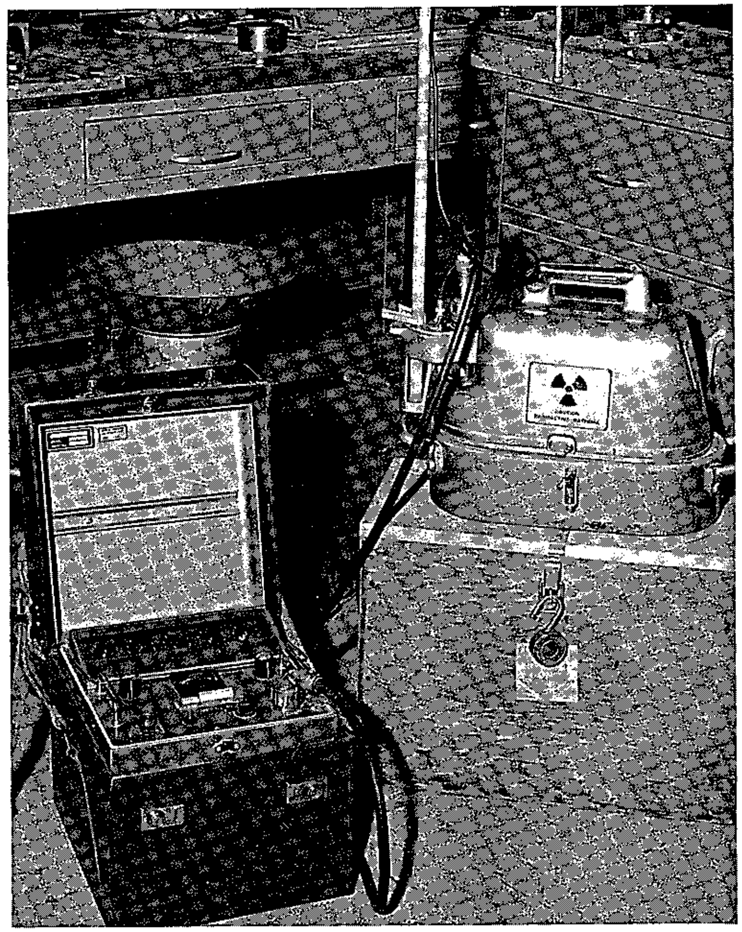


Photo 48. Hidrodensimeter, HDM-2 density/moisture gage

California Moisture/Density Apparatus

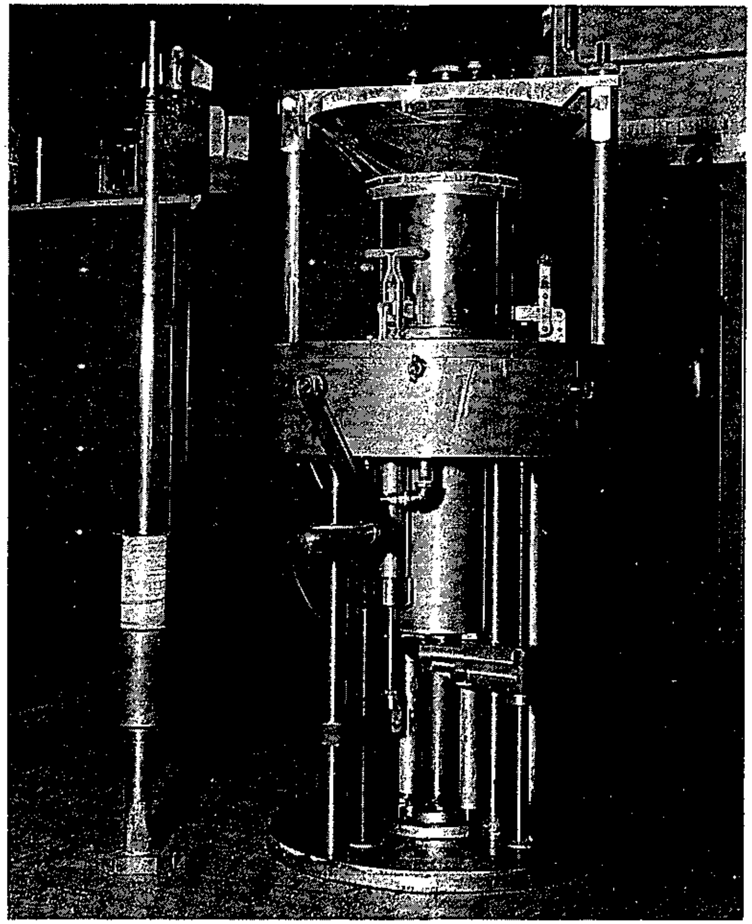


Photo 49. Apparatus and tamper

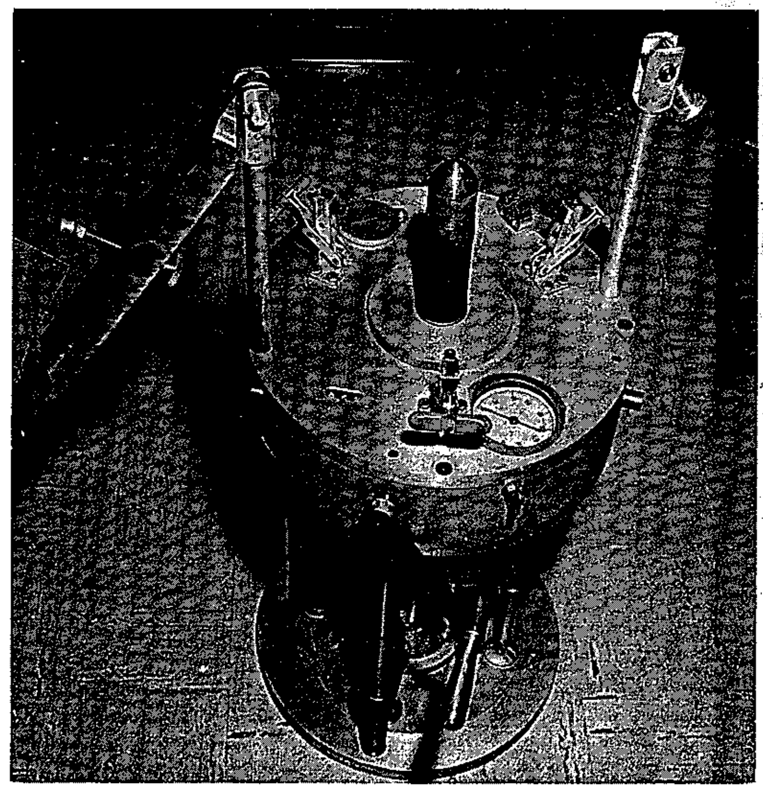


Photo 50. Mold removed to show hydraulic sleeve.

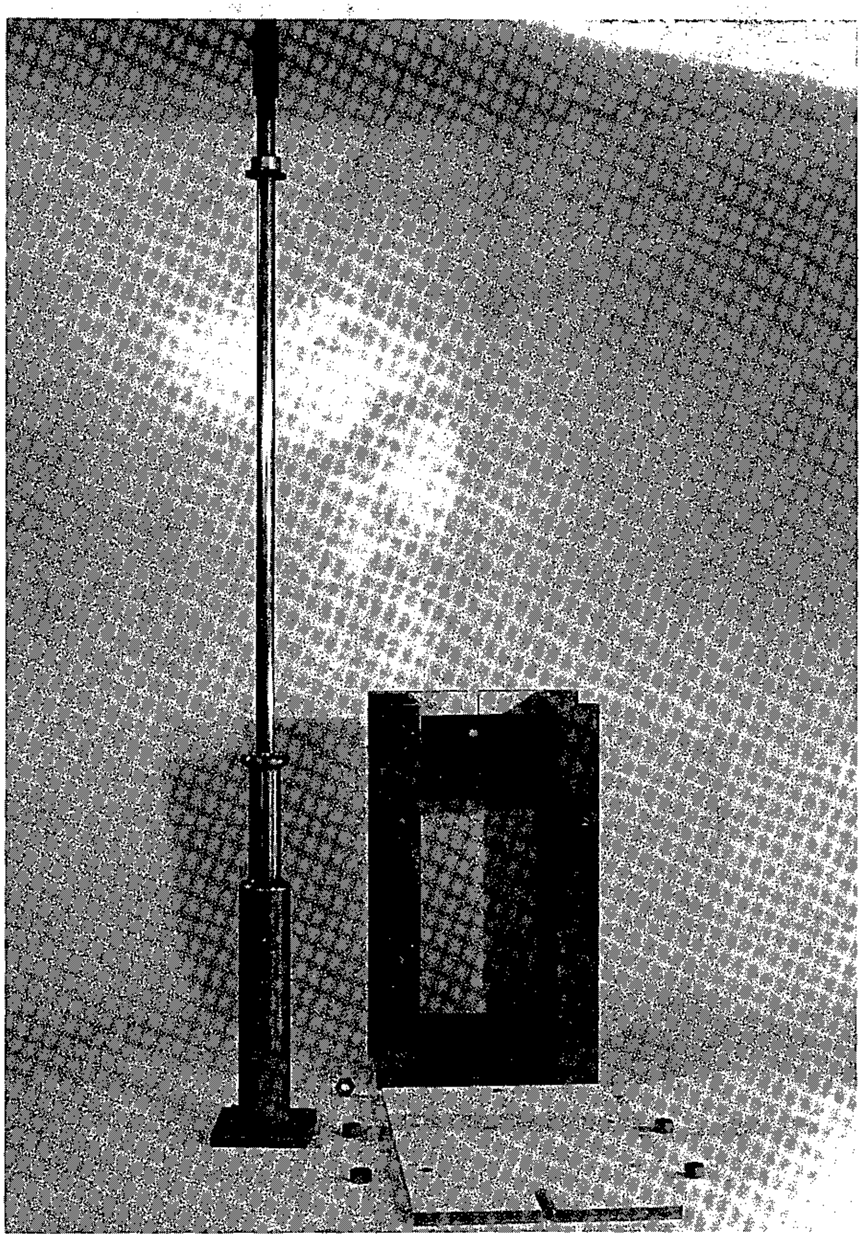


Photo 51. Big Mold and Tamper

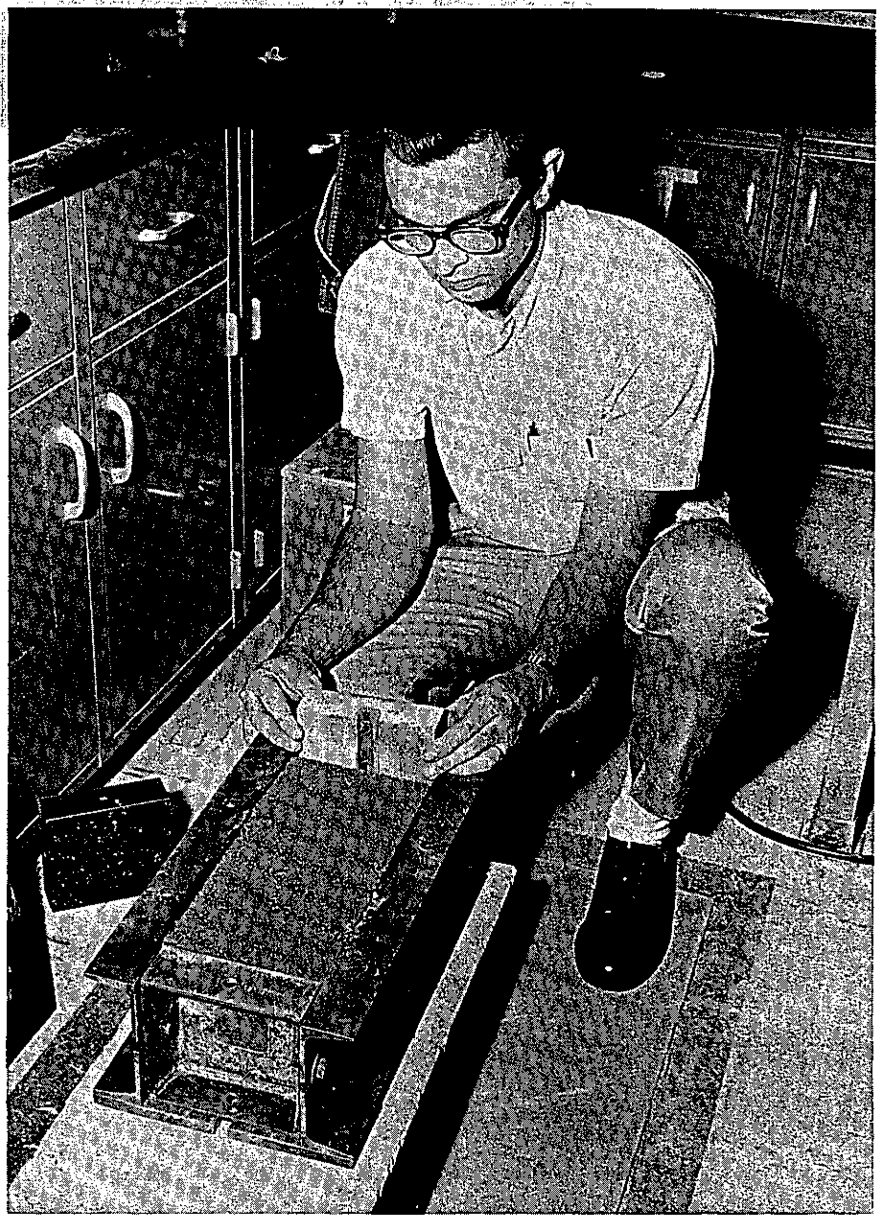


Photo 52. Placement of the shield block at the end of the specimen in the Big Mold.

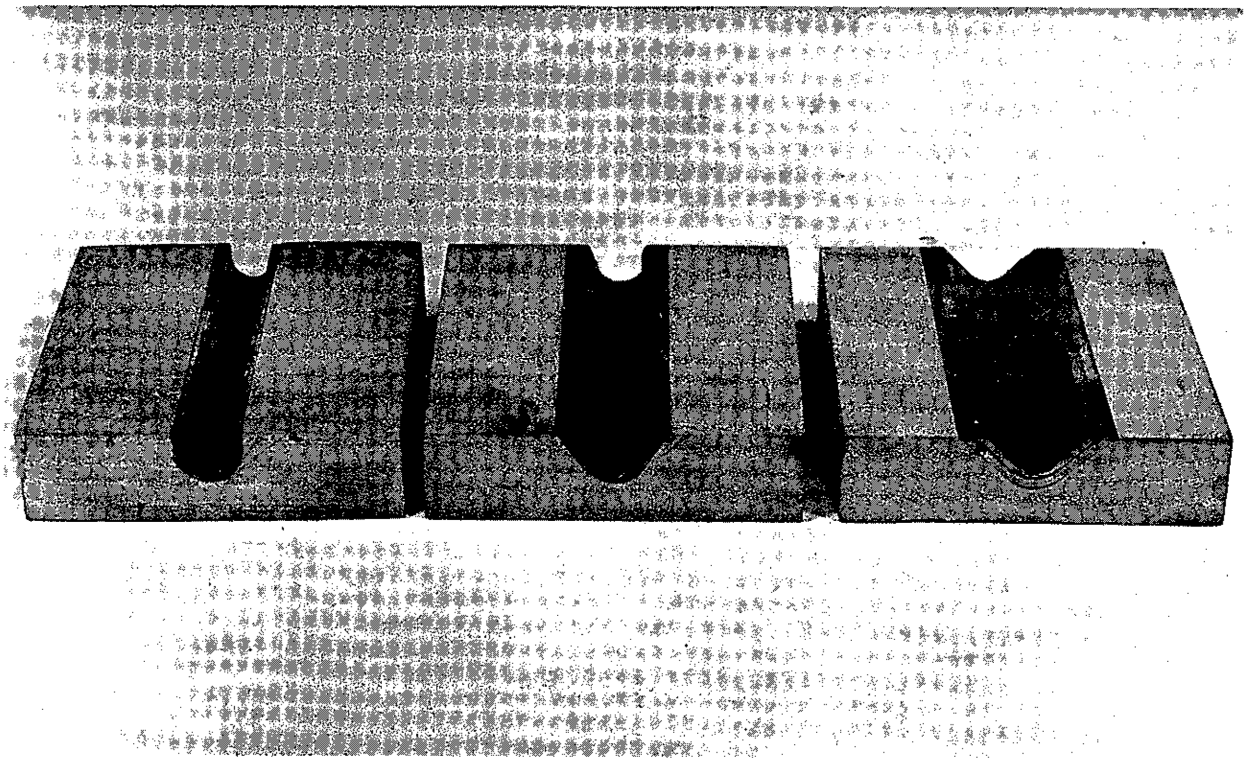


Photo 53. Variations in the configuration of the various shield blocks tried.

Figure 54

COMPARISON OF CMD WITH CALIFORNIA IMPACT DRY DENSITIES

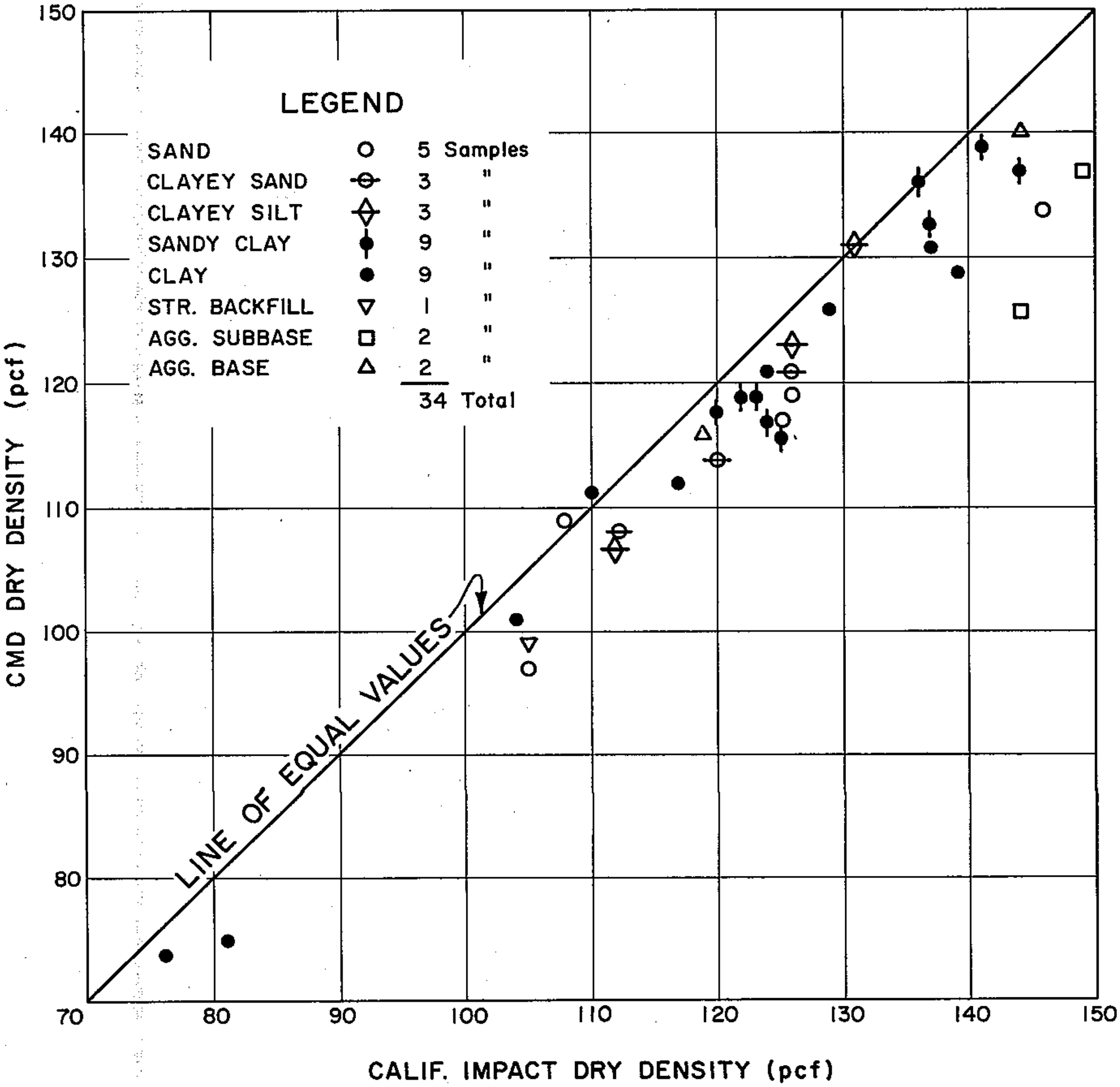
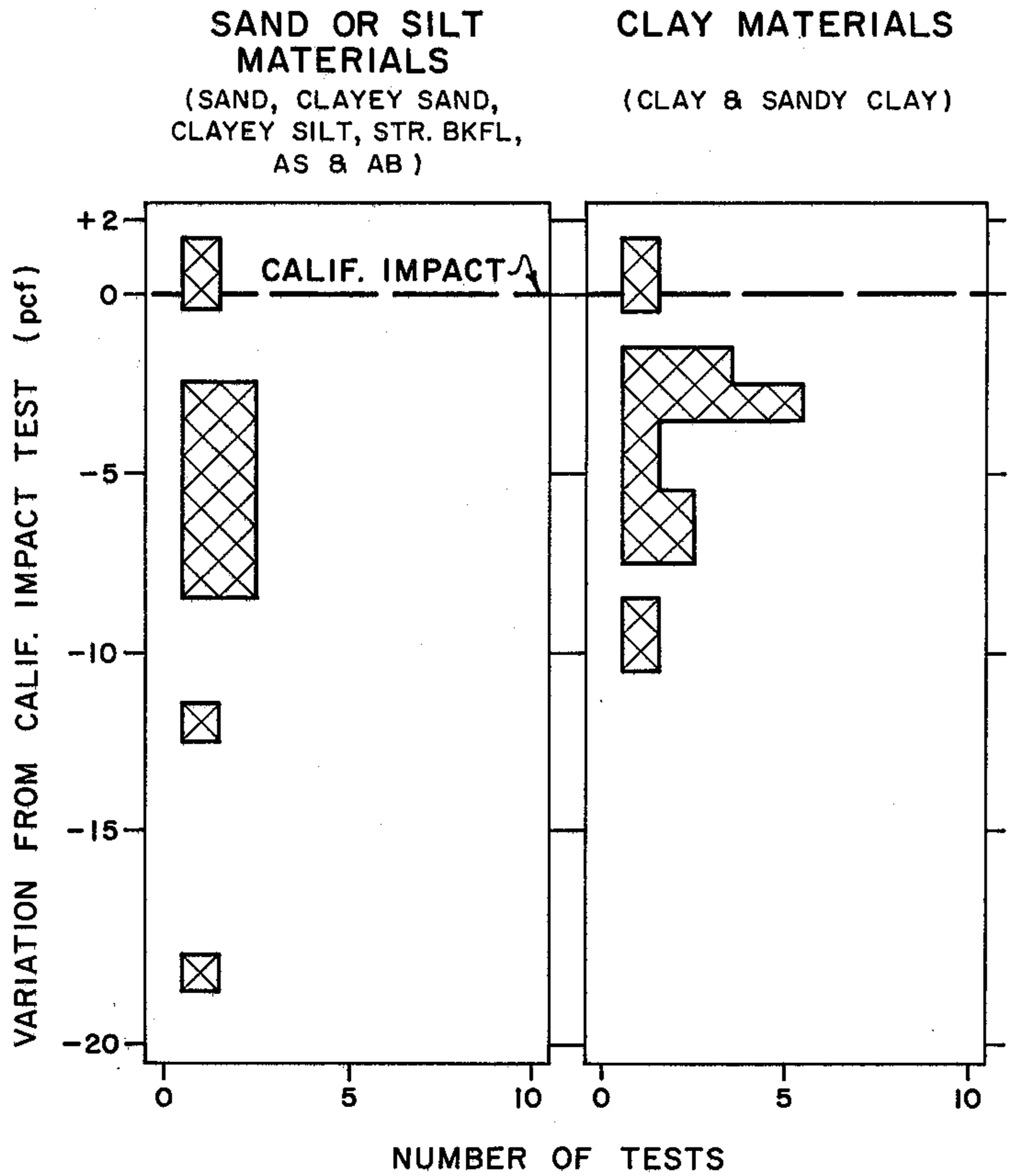


Figure 55

FREQUENCY DISTRIBUTION OF VARIATIONS OF CMD TESTS FROM THE CALIF. IMPACT TEST



APPENDIX A

OPERATING PROCEDURE
FOR
CALIFORNIA SOILS MOISTURE-DENSITY APPARATUS

I. Calibration of Center Rubber Diaphragm

A. Put 6" steel sleeve over diaphragm.
B. Turn crank until 100 psi is registered and note number of turns.
C. Back off crank one turn and 0 psi should be read. (If 0 psi is not read, bleed valves and lines of air and repeat calibration process).
D. Put 0 turns on indicator.

II. Compacting Procedures

A. Place the 2-inch diameter ring over the upper 2" of rubber diaphragm.
B. Turn crank to put half turn on turn indicator.
C. Weigh material scalped on 1-inch screen and place approx. half of the material in mold.
D. Rod sample 20 times with 3/8" bullet nosed rod.
E. Compact sample with tamper for 20 blows.
F. Back off crank to remove 2" sleeve and put back the half turn on indicator.
G. Place remainder of material in mold and compact in same manner as first lift.
H. Place leveling off follower on sample and secure follower with the retaining bar.
I. Turn crank to 100 psi and record number of turns.
J. Back off the turns to the original half turn and remove the bar securing the follower and sample.
K. Give 5 leveling off blows and record height of sample.
L. Using the mold with nuclear source; take 2 readings for the nuclear test count. Two standard counts are taken, one before compacting and one after the sample is removed. The standard count is taken with lead shield removed and nothing in the mold.
M. Remove sample from mold and take a moisture sample to oven dry.
N. With special circular scale, convert information to wet density.

APPENDIX B

A. OPERATING PROCEDURE FOR THE BIG MOLD

I. Assemble the mold.

II. Material

- A. Screen out + 1½ inch aggregate.
- B. Sample size varies from 16,000 to 18,000 grams.
- C. Divide sample into seven equal portions.

III. Compaction

- A. Place one portion or lift in the mold.
- B. Compact lift with 16 blows of tamper. Be sure of uniform coverage.
- C. Repeat "A" and "B" above for other six lifts.
- D. Place top of mold on sample and apply five leveling blows.
- E. Record height of sample, measure from the top of the mold to the machined spot on the top plate.

IV. Nuclear Readings

- A. Place mold on side and remove top side.
- B. Place gage on sample and take two nuclear test counts. Readings are taken across the compaction planes.
- C. Rotate gage 180 degrees and take two more test counts.

V. Correlation

- A. Disassemble mold.
- B. Weigh sample. Care is taken to weigh all the material from the mold.
- C. Take a quarter section lengthwise from the sample and oven dry for moisture correlation.
- D. Convert specific volume and wet weight of sample to wet density. A specific volume scale is furnished dependent on the height of sample.

B. METHOD FOR FIELD APPLICATION OF THE BIG MOLD

I. Standardize nuclear gage by averaging five or more one-minute counts as in Test Method No. Calif. 231, Section C.

II. Determine nuclear in-place compaction value and moisture value as in Test Method No. Calif. 231, Section D. Express the compaction value in terms of count or count ratio.

III. Test minimum compaction value is determined by taking nuclear readings on compacted Big Mold specimens as shown above under "operating procedure."

Count ratios are determined on these specimens by dividing the standard count into the average count obtained on each specimen.

Moisture readings are also taken and expressed as count ratio.

Sufficient specimens (at least three) are tested to enable construction of a moisture-density count ratio curve. The lowest point on the curve denotes the minimum density count ratio and optimum moisture. This count ratio is the test minimum compaction value.

IV. The relative compaction value for each in-place test is calculated as follows:

$$\text{Relative Compaction Value} = \frac{\text{In-place compaction value}}{\text{Test minimum compaction value}}$$

V. The number and location of nuclear tests are governed by the "area concept" and follow the procedure set forth in Test Method Calif. 231, Section E.